Palaeogeography of Lateglacial Vegetations

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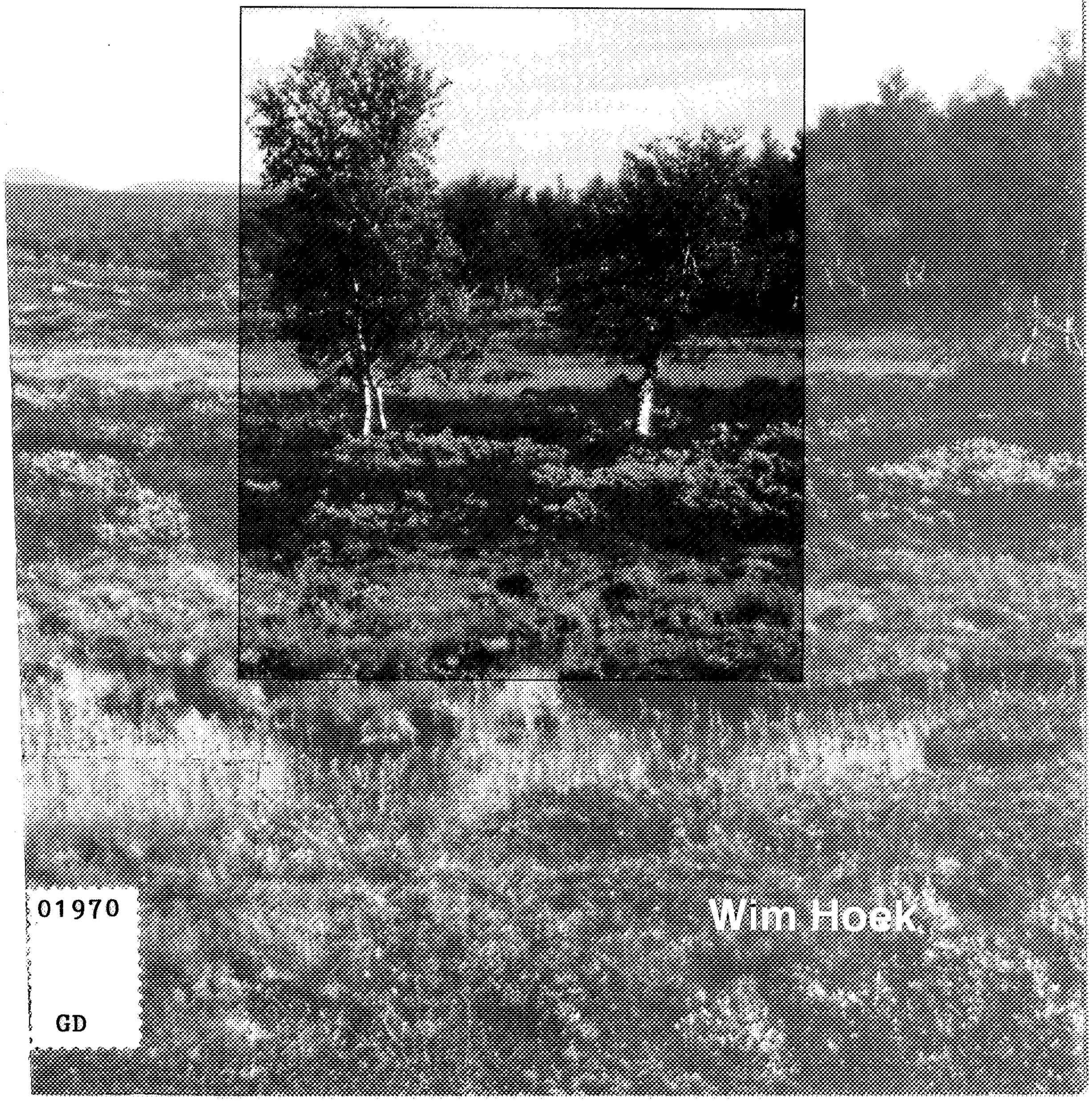
Aspects of Lateglacial and Early Holocene vegetation, abiotic landscape, and climate in The Netherlands



Wim Hoek

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Cover: Birch at Mittåkläppen (Jämtland, Sweden)

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door

Willem Zacharias Hoek

geboren te Culemborg

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copromotor : dr. S.J.P. Bohncke

Prof Dr C.R. Janssen of the Laboratory of Palaeobotany and Palynology, Utrecht University and Dr B. van Geel of the Hugo de Vries Laboratory, University of Amsterdam are gratefully acknowledged for reviewing this thesis.

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1 GENERAL INTRODUCTION

1.1 Introduction

The Weichselian Lateglacial is the transition period between two metastable conditions, that of the last Glacial and that of the present Interglacial and can be placed in time between 13,000 and 10,000 ^{14}C-years BP (Mangerud *et al.*, 1974). The modelling of vegetation, environment and climate during this time-interval, with very dynamic (rapid changing) conditions has its problems, especially because it is difficult to find modern analogue proxy-data for the essentially instable systems of the Lateglacial.
The Lateglacial has been studied frequently by means of palynology, therefore reconstructions of the Lateglacial vegetation and climate have frequently been made. However, palynological investigations on Quaternary climates are in particular directed to single sites. Stratigraphical, palaeoclimatological and palaeoecological conclusions therefore are related to the immediate surroundings of such sites. Comparison with other sites is in practice mainly aimed at comparison of stratigraphic and ecological similarities, e.g. Berglund *et al.* (1996). The influence of abiotic components of the Lateglacial landscape on the vegetation development is poorly known. Major changes in the vegetation will have been the result of climatic changes but vegetation and, more specific, patterns in vegetation have been largely influenced by the abiotic landscape. Environmental reconstructions and ecological interpretations must be considered simultaneously for the if diverse patterns observable in biostratigraphy are to be understood in terms of causal processes (see also Birks, 1986). A palaeogeographical approach can give an additional, independent solution to these problems. Palaeogeography can be applied if a substantial number of well-dated sites over a geographically larger area are available.
This study emphasizes the importance of a better understanding of the functioning of the Lateglacial environment, based on a multi-disciplinary palaeogeographical approach. Divided into two parts, the Lateglacial natural history of The Netherlands is reviewed.

In the first part, aspects of the Lateglacial and Early Holocene vegetation, abiotic landscape and climate in The Netherlands are discussed. In this part, divided into 7 chapters, a critical evaluation is presented considering the relationships between climate, the abiotic landscape and the vegetation development in The Netherlands during the Lateglacial and Early Holocene. Several chapters have been prepared for publication in international journals.

The second part consists of an atlas of the Lateglacial and Early Holocene landscape and vegetation in The Netherlands, together with an extensive review of available palynological data. Landscape and pollen distribution maps of (selected) plant taxa for different time-windows during the Lateglacial and Early Holocene in The Netherlands are presented. Iso-pollen maps and pollen abundance maps show the changes in vegetation composition and patterns in time and space. A selection of pollen diagrams from different regions with selected species is added. The review of the Lateglacial and Early Holocene pollen diagrams in the Netherlands and adjacent regions gives a compilation of over 500 pollen diagrams from the period under consideration. This atlas with review of the available palynological data will be published separately.

1.2 Scope

Recently, within the framework of **IGCP-158B** – *Palaeohydrological Changes in the Temperate Zone in the Last 15,000 Years* – regional syntheses of palaeoecological events have been compiled for **IGCP** type-regions in Europe (Berglund *et al.*, 1996).
The project **IGCP-253** – *Termination of the Pleistocene* – and especially its sub-project – *North Atlantic Seaboard Programme* (**NASP**) – has been concerned with the history of environmental changes in areas adjacent to the North Atlantic during the last glacial-interglacial transition (Lowe, 1994). Regional syntheses of environmental changes have been compiled for the Weichselian Lateglacial within this programme (Bohncke, 1993; Lowe *et al.*, 1994, 1995; Walker *et al.*, 1994 and Walker, 1995). In these syntheses only minor attention has been given to the relationship between the abiotic landscape and the Lateglacial vegetation development. The integration of terrestrial, marine and ice-core records is becoming more important for unraveling the climate history during particularly the last Glacial-Interglacial transition (Lowe *et al.*, 1995). Furthermore, a multi-proxy approach for terrestrial records, which combines different lines of evidence for the reconstruction of past climate, provides refined records of climate change (Huijzer and Isarin, 1997). Especially *The Younger Dryas* time-interval (11,000 - 10,000 ^{14}C BP) is an important subject of study (Troelstra *et al.*, 1995; Renssen, 1997; Isarin, 1997). For the correlation between records from different environments and of different signature, a chronological framework for the Lateglacial and Early Holocene period is, however, indispensable (Björck *et al.*, 1996). The development of databases containing all kinds of information (e.g. European Pollen Database, Lake Level Database) is a promising step forward for future investigations.
The present study emphasizes the relationships between vegetation, abiotic landscape and climate. Furthermore, the chronology and spatial distribution of the Lateglacial and Early Preboreal vegetation in The Netherlands is considered in detail. In order to facilitate comparison with other studies, ages presented in this study are given as uncalibrated ^{14}C-years BP. The palynological data used in this study have been inserted into a relational database structure, in cooperation with the European Pollen Database.

1.3 Historical perspective

After the recognition of the Allerød and Bølling oscillations in the pollen diagram Hijkermeer (van der Hammen, 1949), the study of Lateglacial vegetation patterns in The Netherlands continued with the dissertation of van der Hammen (1951). He constructed the first maps that showed differences in pollen composition over the Netherlands (figure 1.1).
In the early seventies the idea of a further investigation of the Lateglacial vegetation development in The Netherlands was proposed. Zagwijn (Geological Survey, Haarlem), van der Hammen (University of Amsterdam), Janssen (University of Utrecht), Teunissen (University of Nijmegen) and Maarleveld (Soil Survey, Wageningen) prepared lists of pollen diagrams which encompass the Lateglacial time-interval. A total 131 pollen diagrams appeared in the lists provided by the different institutes. However, the compilation was never completed, mainly because of technical problems in comparison between different pollen diagrams which were constructed using incomparable pollen sums. The lists provided by these authors nevertheless formed a starting point for the present study. Since then, more pollen diagrams have been produced which for the greater part have been used in this study.

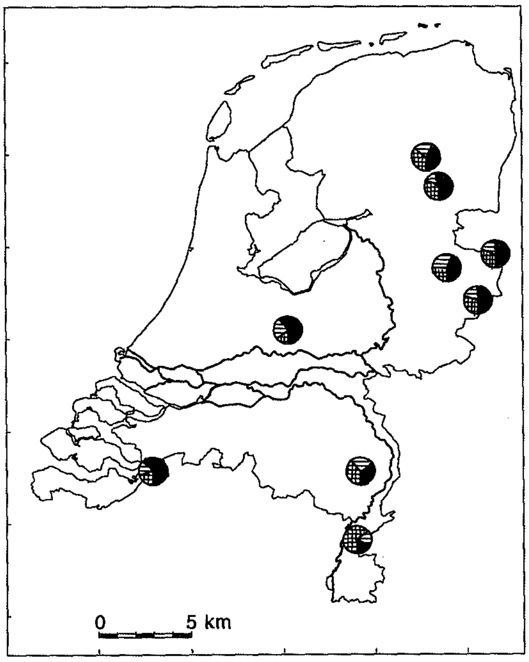

Figure 1.1 Pollen-spectra-map of The Netherlands for the Allerød time (after van der Hammen, 1951), hatched: herbs and Ericales, cross-hatched: *Betula* and *Salix*, filled: *Pinus*.

1.4 Approach

The principal aim in this study was to use palaeoecological data in a palaeogeographical way in the analysis of Weichselian Lateglacial relationships between vegetation, environment and climate. To achieve this goal, a large number of observation points were required, which for comparison needed to be correlated in time.

The first step was to establish a regional database of palynological data from a range of palaeo-environments. The investigations were initially limited to The Netherlands and surroundings, reaching to Ireland and western Poland as geographical extremes. This area has much in common as to lithology and geomorphology, being largely a lowland region. On the other hand there is also enough variation in substrates and relief to cause significant differences in the palaeo-pollen rain. Originally it was expected that pollen diagrams from about 150 sites in the Netherlands would be available (published and unpublished). However the inventory during the years has resulted in over 400 Lateglacial sites in The Netherlands only. A total of 260 pollen diagrams has been compiled so far and the pollen data have been inserted into a relational database.

As the second step all pollen diagrams from the sites in the database have been computed and drawn with the help of the TILIA and TILIA-graph programs (Grimm, 1992), in order to make also visual comparison of the diagrams possible. With the help of bio-stratigraphic marker horizons and radiocarbon dates a regional zonation has been developed which enabled the time-stratigraphical correlation between the different pollen diagrams.

The third step was to study relationships between palaeo-vegetation and various environmental factors (lithology, geomorphological situation, climate) and examine these relations threedimensionally, in time and space, in order to get an insight into the interaction of biotic and abiotic parameters during different time-intervals of the Lateglacial. On the basis of a considerable number of palynological investigations, iso-pollen maps have been constructed, in order to visualize the vegetational development. These permitted analysis of the relationships between vegetation and abiotic factors in time and space.

Furthermore, a multi-disciplinary study of the Lateglacial calcareous deposits at Gulickshof (southern Netherlands) was undertaken to serve as a standard for the southern part of the study area. AMS dated terrestrial plant remains provided a chronological framework for the regional vegetation development and the formation of the calcareous deposits. Aquatic pollen taxa together with mollusc assemblages provide an insight in the changes in the local limnic environment over the period under study. Besides, these calcareous deposits gave the opportunity to perform stable isotope analysis ($\delta^{18}O$ and $\delta^{13}C$) on the carbonates.

1.5 Cooperation

Cooperation with other institutes has proved to be of great importance for the establishment of the Lateglacial palynological database. The palynological data from The Netherlands used in this study were provided by the following institutes; The Netherlands Geological Survey (RGD, now NITG-TNO, Haarlem), DLO Staring Centre (Wageningen), Hugo de Vries Laboratory (University of Amsterdam), Laboratory for Palaeobotany and Palynology (Utrecht University), Institute for Prehistory (University of Leiden), Groningen Institute of Archeology (University of Groningen) and the Faculty of Earth Sciences (Vrije Universiteit Amsterdam). Cooperation with scientists from other geological disciplines greatly improved the insight in the functioning of the Lateglacial landscape as a whole. In this project international cooperation has been established with the European Pollen Database (Arles, France). Besides, the Laboratory for Palaeo-ecology and Landscape-evolution (University of Gent, Belgium) and Niedersächsisches Institut für historische Küstenforschung (Wilhelmshaven, Germany) provided data which have been included into the database.

1.6 Chapter outline

After the general introduction and chapter outline of this study, presented in chapter 1, different aspects of the Lateglacial and Early Holocene vegetation, abiotic landscape and climate in The Netherlands are outlined.

An introduction to the Weichselian Lateglacial vegetation is given in chapter 2. The vegetation development is considered in a biostratigraphical sense. A general zonation for the Lateglacial and Early Holocene pollen diagrams has been developed, which is based on corresponding trends in the regional pollen component. Problems concerning definitions and sub-divisions of the Lateglacial in general are discussed. A comparison with the vegetation development in The Netherlands and the neighbouring countries is made. For northern Germany, discrepancies occur in the biostratigraphical terminology for particularly the earliest part of the Lateglacial in relation to that of The Netherlands. In the discussion, written together with W.H. Zagwijn, a solution for this confusion is presented.

In chapter 3 is demonstrated that a close relationship exists between climate and regional vegetation development during the Lateglacial in the Netherlands. The Lateglacial and Early Holocene vegetation development in The Netherlands is considered in a chronological context. A critical review of all available radiocarbon dates from over 100 pollen diagrams has led to a chronostratigraphical framework for the Netherlands and direct surroundings. The regional pollen assemblage zone boundaries were pin-pointed to the radiocarbon time-scale with the help of ^{14}C-intensity curves. Furthermore, an attempt has been made to relate the dated regional vegetation trends to larger scale climatic oscillations, as recorded in oxygen isotope curves from the Greenland ice cores and Swiss lake sediments. The paper will be published in *Vegetation History and Archaeobotany*.

In chapter 4 the abiotic landscape evolution in The Netherlands during the Weichselian Lateglacial is outlined. Lateglacial abiotic landscape types and the geomorphological features in the different landscape types are considered. The interaction between the vegetation and the Lateglacial abiotic landscape is evaluated, showing the close relationship between those components. It will appear that the knowledge of the vegetation development is significant to understand the landscape development as a whole. This chapter is in preparation for *Geologie & Mijnbouw*.

In chapter 5 is demonstrated that there is a significant influence of the abiotic landscape on the vegetation patterns during the Lateglacial in The Netherlands. The patterns of three distinct Lateglacial taxa in The Netherlands for specific time windows are used to demonstrate the relationship between the iso-pollen patterns and the abiotic landscape. The preparation of the palynological data and the construction of the iso-pollen maps is outlined. Selected maps for *Juniperus*, *Pinus* and Ericales show the variation in distribution in a spatial context. A comparison is made with a map of the Lateglacial abiotic landscape types of the Netherlands. The paper will be published in *Eiszeitalter und Gegenwart*.

In chapter 6, a multi-disciplinary case-study of the Lateglacial site Gulickshof is presented. This study of the Lateglacial calcareous gyttja deposits near Susteren, southern Netherlands, resulted in a high resolution pollen diagram, comparable to many other classical investigations. The multi-disciplinary aspect is, however, rather new for The Netherlands. Beside the regional and local vegetation development, together with a detailed chronostratigraphy, the 2 meters thick deposit of calcium carbonate precipitates opens-up the opportunity to study water quality and stable isotopes. Stable isotope and mollusc data provide us with important additional information about the Lateglacial environmental changes. Especially the reconstructed changes in water level appeared to add new insight in the vegetation composition. This chapter, written together with S.J.P. Bohncke, G.M. Ganssen and T. Meijer, is in preparation for *Boreas*.

A review of the environmental and climatic changes during the Lateglacial and Early Holocene in The Netherlands is presented in chapter 7. The changes in climate, vegetation and abiotic landscape are considered in a time-stratigraphical context. Aeolian and fluvial processes and lake-level changes are correlated with the vegetational record and temperature reconstructions based on Coleoptera and plant climate indicator species. This chapter, written with S.J.P. Bohncke, will be published in a revised form in *Fairbridge Encyclopedia of Quaternary Geology*.

2 LATEGLACIAL AND EARLY HOLOCENE VEGETATION DEVELOPMENT IN THE NETHERLANDS: A BIOSTRATIGRAPHICAL SUB-DIVISION

2.1 Introduction

For the comparison of pollen diagrams, biostratigraphy has been the most frequently used method since the introduction of palynology as a tool for vegetation and climate reconstruction. The palynological sub-division of the Weichselian and especially the Weichselian Lateglacial established by Jessen (1935) and Iversen (1942), was introduced for The Netherlands by van der Hammen (1949). In a pollen diagram obtained from a Pleniglacial pingo remnant named Hijkermeer, van der Hammen recognized the interstadial Bølling and Allerød oscillations (figure 2.1). The interstadial deposits were characterized by a higher content of organics in relation to the stadial deposits. In his dissertation, van der Hammen (1951) was able to prove a similar vegetation development at different locations in The Netherlands based on this sub-division of the Lateglacial. Since then, hundreds of pollen diagrams from Lateglacial and Early Holocene deposits were constructed and sub-divided following this work.

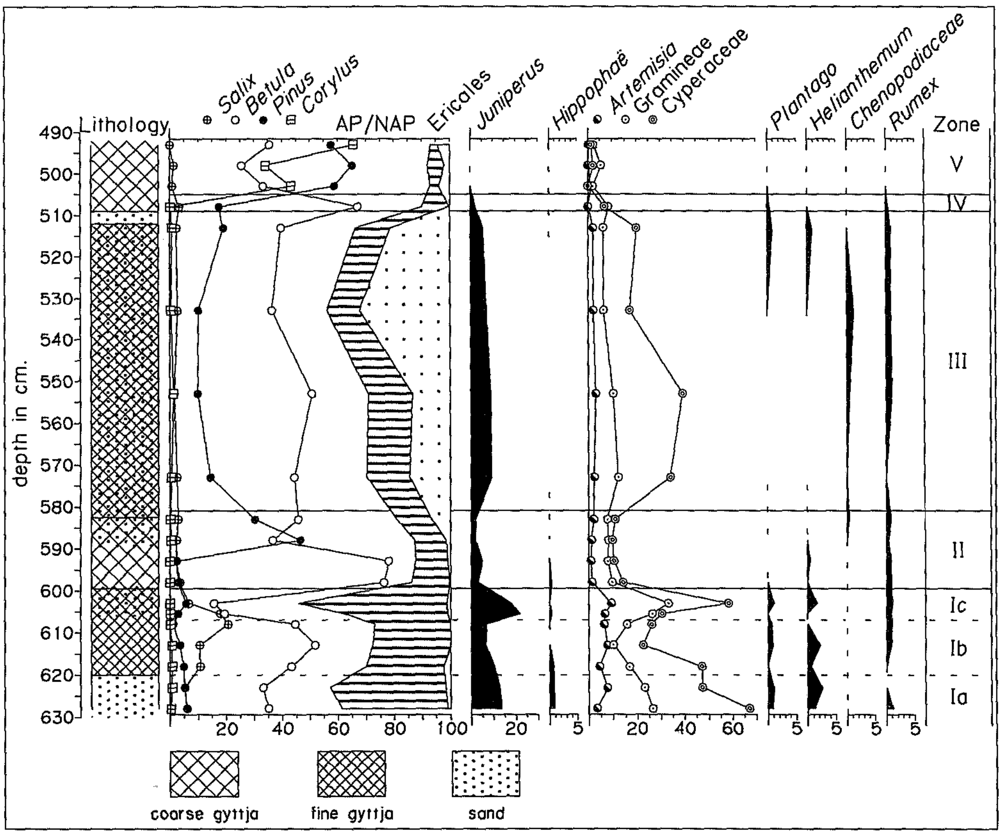

Figure 2.1 Interstadial Bølling (Ib) and Allerød (II) oscillations in pollen diagram Hijkermeer (modified after van der Hammen, 1949).

With the introduction of the radiocarbon dating method, biostratigraphic correlation became less important and pollen diagrams were considered more frequently in a chronological context. Pollen diagrams remain, however, an important means for checking the radiocarbon data. Pollen diagrams without radiocarbon time-control, however, can only be compared to other pollen diagrams on the basis of regional biostratigraphy. A dense pattern of Lateglacial locations investigated by means of palynology is used to reconstruct vegetation patterns for different time-windows during the Lateglacial (Hoek, 1997). For the time-correlation of this large number of pollen diagrams used in the palaeogeographical vegetation reconstruction, biostratigraphy has been used. In this chapter, the emphasis is on the construction of a regional biostratigraphic framework. Besides, a regional chronological framework has been constructed with the help of radiocarbon dated pollen diagrams from The Netherlands and surroundings (see chapter 3). According to this chronological study, the regional vegetation development can be considered in a time stratigraphical context and thus correlated with other proxy-records that are dated by means of radiocarbon.

2.2 Study area

For the construction of a regional biostratigraphy, uncertainties in different factors influencing vegetation development should be as small as possible. This means that spatial variations in climate, which are important in vegetation development, but are difficult to measure must be minimized. This can be achieved if a relatively small area with a large density of observations is considered. Within The Netherlands and adjacent areas the climate conditions were quite similar during the Lateglacial. Figure 2.2 shows the relatively continental setting of The Netherlands during the Weichselian Lateglacial (modified after Jelgersma, 1979 and Lang, 1994).

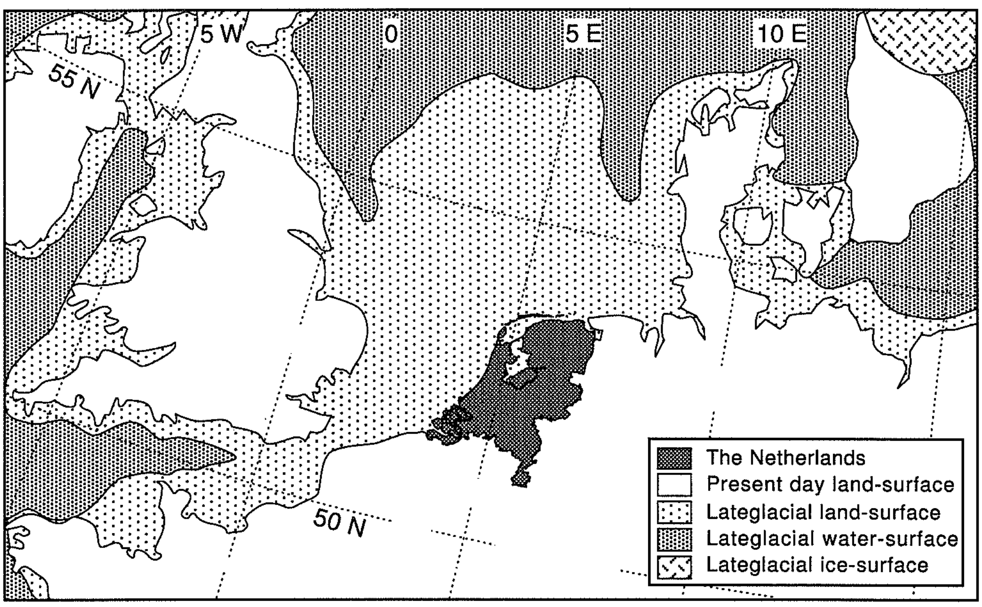

Figure 2.2 The relative continental setting of The Netherlands during the Weichselian Lateglacial (modified after Jelgersma, 1979 and Lang, 1994).

As sealevel was between 90 and 65 meters below the present date level (Jelgersma, 1979), the coastline was more than 200 kilometers away and any climate gradient induced by the sea is negligible for The Netherlands during the time under investigation. Therefore, it might be expected that in The Netherlands there should be only minor spatial differences in climate during the Weichselian Lateglacial due to the small area and relatively large distance to the former coastline. It is assumed that, regional vegetation development in The Netherlands, as far as it was climatically induced, can be expected to be approximately synchronous, as the maximum distance between data points in the north and south is only 250 kilometers.
It is obvious that single pollen diagrams will represent certain local influences. The main reason for this is the fact that not only the large scale changes in climate determined the vegetation development. Also more local variations in lithology, geomorphology and geohydrological conditions have influenced the vegetation development and patterns (see chapter 5).
In The Netherlands these abiotic environmental conditions have been investigated in various studies and the abiotic landscape that existed during the Lateglacial is therefore well-known. The Lateglacial abiotic landscape is discussed in chapter 4.

2.3 Regional biostratigraphical zonation

2.3.1 Available data

Over 400 palynological records have been investigated in The Netherlands by several institutes over the last decades, covering part or whole of the Weichselian Lateglacial. Locations of the palynologically investigated sections are shown in figure 2.3. Pollen diagrams dated by means of radiocarbon from northern Belgium and north-western Germany have also been used for the biostratigraphical zonation.
For the biostratigraphical zonation, the palynological data from records used in this study were entered directly from the counting sheets into a computer. The data are stored in a PARADOX® relational database, using the European Pollen Database structure. In figure 2.3, the more than 250 pollen diagrams inserted into the database are presented by filled-in, the others by open symbols.
For the construction of pollen diagrams a uniform pollen sum was used to calculate percentages, thus providing diagrams that allow for comparison on a similar calculation base. In this pollen sum only Lateglacial tree taxa, shrubs and dry herbs are included, i.e. the group of regional terrestrial taxa according to Janssen (1973). The local pollen taxa, aquatics and riparian herbs including Cyperaceae, as well as spores and thermophilous tree pollen, were excluded from the pollen sum. The countings were saved as TILIA percentage-files, and subsequently uniform pollen diagrams were drawn, using TILIAGRAPH 1.20 (Grimm, 1992).

2.3.2 Biostratigraphical marker horizons

The lower and upper boundary of the Lateglacial can be defined on palynological grounds. The lower boundary is according to van der Hammen (1951) characterized by the rise in the *Artemisia* curve, being the first clear sign of a climatic amelioration. *Artemisia* was already present during the cold Pleniglacial and the increase in percentage was not a result of immigration of this taxon. On approximately the same grounds, *Betula*, which was present since the early part of the Lateglacial in The Netherlands, was responding to the climatic amelioration at the beginning of the Holocene. Furthermore, a regressive vegetation development caused by a deterioration in climate is considered to be isochronous. For instance, the *Pinus* fall recorded in many pollen diagrams, marking the end of the Allerød in The Netherlands is considered to be a good time marker. Even fluctuations in *Betula* percentage during the Lateglacial in The Netherlands might be synchronous (see chapter 3). Other biostratigraphical marker horizons which have been used in the zonation of the pollen diagrams are discussed in the next section.

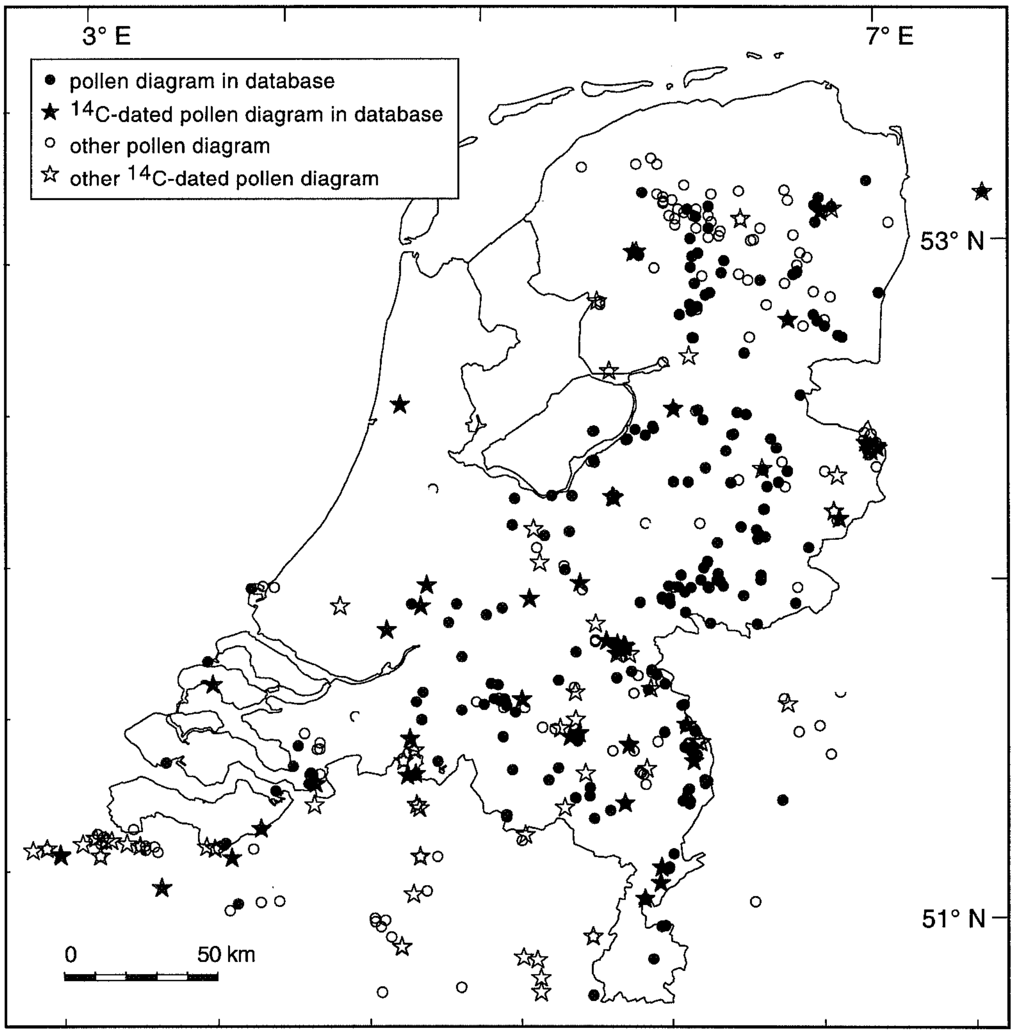

Figure 2.3 Locations of the palynologically investigated sections with Lateglacial or Early Holocene deposits.

2.3.3 Zonation

Major shifts in the main pollen taxa, radiocarbon dated in several pollen diagrams distributed over The Netherlands, are used to construct a regional zonation. Only those taxa that determine the vegetation aspect and may reflect regional trends are used for biostratigraphical zonation of the diagrams. Janssen (1980) has discussed different stratigraphical zonation concepts for the division of pollen diagrams. In the present study, most important in the zonation are the fluctuations in *Betula* and *Pinus* percentages. Shifts in the percentages of Arboreal Pollen (AP), Non Arboreal Pollen (NAP), *Salix*, *Juniperus*, *Populus*, *Artemisia* and *Empetrum* were also used for the zonation. The zonation of the pollen diagrams used in this study sometimes differs from that given by the original authors, who were at that time not able to use many locations for regional comparison and often used different pollen sums or zonation concepts. The biostratigraphical zones are named following Hedberg (1976), therefore adjectives such as Early and Late are used instead of Older and Younger. The use of this terminology has the advantage that no confusion with the chronozones presented by Mangerud *et al.* (1974) can be made (see also Walker, 1995).
The following Pollen-assemblage zones can be distinguished in The Netherlands for the Lateglacial and Early Holocene.

LP NAP Pollen-assemblage Zone (Late Pleniglacial)
1 *Betula-Salix* Pollen-assemblage Zone (Early Dryas *s.l.*)
2 *Betula-Pinus* Pollen-assemblage Zone (Allerød)
3 NAP-*Empetrum* Pollen-assemblage Zone (Late Dryas)
4 *Betula* Pollen-assemblage Zone (Early Preboreal)
5 *Pinus* Pollen-assemblage Zone (Late Preboreal)

Some of these zones can be divided into sub-zones at different levels of biostratigraphic resolution. In the database numerical codes at three levels indicate the division into zones and sub-zones. A summary of the zonation scheme with zone codes and the main palynological characteristics of zones and sub-zones is given in table 2.1. Changes in percentage are presented as arrows, with a relatively big change represented by double arrows. With the help of 239 carefully selected radiocarbon dates derived from 102 pollen diagrams from The Netherlands, northern Belgium and western Germany the regional vegetation zones have been attached to the uncalibrated radiocarbon time-scale (see chapter 3).

2.4 Zone description

2.4.1 Zone LP (older than 12,900 BP)

Zone LP (NAP PaZ), represents the end of the Late Pleniglacial, the period preceding the Lateglacial. Only a very few locations contain organic deposits belonging to zone LP.
Most samples from this zone are relatively poor in pollen, indicating low pollen production or high sediment accumulation rates. The palynological characteristics of this zone are high percentages of NAP, mainly Gramineae, and very low percentages of *Artemisia*. In some cases relatively high percentages of *Pinus* occur, probably as a result of long distance transport. Reworking from older deposits also causes *Pinus* and thermophilous trees to be

table 2.1 Regional pollen zonation scheme for the Lateglacial and Early Holocene in The Netherlands (↑=increase, ↑↑=strong increase, ↓=decrease, ↓↓=strong decrease).

age BP	zone level1	sub-level2	sub-level3	pollen percentage characteristics
	5	5	5	
9,500	-------	-------	-------	*Pinus* ↑↑
	4	4c	4c	
9,750		-------	-------	*Betula* ↑, *Populus* ↑
	4	4b	4b	
9,950		-------	-------	*Betula* ↓, Gramineae ↑, AP ↓
	4	4a	4a	
10,150	-------	-------	-------	*Betula* ↑↑, *Juniperus* ↑, NAP ↓
	3	3b	3b	
10,550		-------	-------	*Empetrum* ↑
	3	3a	3a	
10,950	-------	-------	-------	*Pinus* ↓, *Betula* ↓, AP ↓, NAP ↑
	2	2b	2b	
11,250		-------	-------	*Pinus* ↑↑
	2	2a	2a2	
11,500			-------	*Betula* ↓, *Pinus* ↑, *Juniperus* ↓
	2	2a	2a1	
11,900	-------	-------	-------	*Betula* ↑↑, *Salix* ↓, AP ↑↑, NAP ↓↓
	1	1c	1c	
12,100		-------	-------	*Betula* ↓, *Salix* ↑, *Juniperus* ↑, NAP ↑
		1b	1b	
12,450		-------	-------	*Betula* ↑, AP ↑
	1	1a	1a	
12,900	-------	-------	-------	*Artemisia* ↑
	Late Pleniglacial (LP)			

found in relatively high values, especially in those frequent cases where the Late Pleniglacial deposits consist mainly of mineroclastic waterlain sediments. Palynological indications for this zone suggest a rather open vegetation which consisted mainly of grasses and sedges.

2.4.2 Zone 1 (12,900 - 11,900 BP)

Zone 1 (*Betula-Salix* PaZ) is characterized by an increase of *Artemisia* percentages and AP rising towards 50%. High percentage values of other heliophilous herbs as *Helianthemum* and *Plantago* are indicative for this zone. Cyanobacteria of the *Gloeotrichia*-type supposedly played a major role in the fixation of nutrients (van Geel *et al.*, 1989) while algae might have initiated stabilization of the substrate. Pollen of shrubs such as *Hippophaë rhamnoides* and *Juniperus communis* as well as *Betula* and *Salix* trees appears sequentially during this zone. The low AP percentage and abundance of heliophilous herbs during zone 1 indicates an open vegetation type. Zone 1 can be divided into three subzones; 1a-c.

The first sub-zone, 1a (12,900 - 12,450 BP), is characterized by an increase in the *Artemisia* pollen percentage. Van der Hammen (1951) noted that the beginning of the Lateglacial can be defined palynologically by the rise in the *Artemisia* curve. The percentages of arboreal pollen types are still low with values below 20%. The low arboreal pollen percentages indicate an open landscape with some *Betula nana* shrubs. In plant formational terms this sub-zone reflects a transition from tundra towards shrub-tundra. Sub-zone 1a can be considered equivalent to the Earliest Dryas zone as defined by van Geel *et al.* (1989).
The second sub-zone, 1b (12,450 - 12,100 BP), starts with an increase in *Betula* tree pollen. During this zone the percentage of arboreal pollen types rises to values around 50%. The rise in arboreal pollen values is mainly the result of expansion of dwarf birch shrubs (*Betula nana*) and birch trees. This develops towards a vegetation of small birch copses within a predominantly open landscape. Sub-zone 1b can be considered equivalent to the Bølling zone, Bølling *sensu stricto*, as defined by van Geel *et al.* (1989).
At the start of sub-zone 1c at 12,100 BP *Betula* decreases in percentage while NAP values rise. Towards the end of this sub-zone *Salix* percentages rise, in many cases towards values higher than those of *Betula*. The percentages of *Juniperus* also reach a maximum towards the end of this sub-zone. The palynological evidence suggests that the vegetation again became more open. A minerogenic influx in this period supports the palynological indication of a more sparse vegetation in a relatively open landscape. The relative importance of *Salix* (willow) shrubs during the later part of this sub-zone may indicate wetter conditions in the basins towards the start of the next zone. Sub-zone 1c can be considered equivalent to the Earlier Dryas zone as defined by van Geel *et al.* (1989).

2.4.3 Zone 2 (11,900 - 10,950 BP)

Zone 2 (*Betula-Pinus* PaZ) is characterized by a strong rise in AP to over 80%, while NAP percentages decreased. Heliophilous herbs became less important. Based on differences in the AP composition zone 2 can be divided into two sub-zones; 2a or *Betula*-phase and 2b or *Pinus*-phase. Zone 2 as a whole can be considered equivalent to the Allerød zone as defined by van Geel *et al.* (1989).
At the beginning of sub-zone 2a *Juniperus* pollen is relatively important but subsequently *Betula* is the main tree-pollen component with percentages rising to over 60%. In vegetational terms, juniper scrub developed, preceding the for this sub-zone characteristic open birch forest (Bohncke, 1993). In this sub-zone two minor temporary decreases in *Betula* percentage can be recognized, by which the sub-zone is subdivided into 2a1 and 2a2.
From the start of sub-zone 2a2 (11,500 BP), at the second and most frequently found decrease in *Betula* percentage, percentages of *Pinus* rise to 15%. Towards the end of sub-zone 2a2 *Pinus* percentages again decrease to low values in favour of *Betula*. The fluctuations in *Betula* percentage are more clearly expressed in diagrams with high amounts of *Betula* pollen than in other diagrams. The decreases in *Betula* tree pollen percentage in favour of NAP around 11,700 BP and 11,500 BP imply that the birch forest opened. *Pinus* pollen occurs with higher percentages in the second opening of the forest, caused by long distance transport of pollen from pine trees which had migrated into areas further to the south-east and were already relatively near. In some locations during this phase a sandy influx is registered, also indicating opening of the vegetation.
In sub-zone 2b *Pinus* is relatively important. The rise of *Pinus* percentages to values which

are constantly higher than 20% indicates the start of sub-zone 2b; *Pinus* percentage varies between 20-60% over The Netherlands. The start of sub-zone 2b, marked by the arrival of *Pinus sylvestris* which migrated from the south-east into The Netherlands, is set at 11,250 BP. *Pinus* pollen percentages exceed the rational limit of 20%, indicating that pine was actually growing locally (Lang, 1994).

2.4.4 Zone 3 (10,950 - 10,150 BP)

Zone 3 (NAP-*Empetrum* PaZ) is characterized by a drop in AP percentages and can be divided into two sub-zones; 3a and 3b. Low percentages of thermophilous tree pollen may be present during this zone as a result of reworking from older deposits. Zone 3 as a whole can be considered equivalent to the Late Dryas zone as defined by van Geel *et al.* (1989). The opening of the forest vegetation at the onset of the Late Dryas stadial is set at 10,950 BP; the area of pine reduced at the start of this zone. In the diagrams where *Pinus* percentages are relatively high in the preceding sub-zone 2b, the strong decrease in *Pinus* indicates the start of sub-zone 3a. At locations where pine was a relatively unimportant species, a reduction in birch coverage took place at this time. With this opening of the birch forest, however, the influence of long-distance pollen transport increased. In some cases, therefore, no decrease in *Pinus* percentages and in some occasions even an increase in *Pinus* may be seen. In this situation the start of sub-zone 3a is marked by a decrease in *Betula* (see chapter 6).
The start of sub-zone 3b around 10,550 BP is characterized by a rise in *Empetrum*, while AP percentages fluctuate at a low level. *Empetrum nigrum* (crowberry) was an important species in the vegetation, especially in the northern Netherlands during the second phase of the Late Dryas stadial. The expansion of crowberry coincides with the influx of aeolian sandy material recorded in many pollen diagrams, indicating that the vegetation cover became less dense.

2.4.5 Zone 4 (10,150-9,500 BP)

Zone 4 (*Betula* PaZ) is characterized by an increase in AP percentage, especially *Betula*, to high values. Birch forests became more dense with the start of the Holocene in large areas in NW-Europe (Paus, 1995). This is expressed by high percentages (over 80%) of *Betula* tree pollen in The Netherlands during this period. At some locations the development of juniper scrub occurred preceding the birch forest. Zone 4 can be considered equivalent to the Preboreal zone, as defined by Behre (1966), or the Early Preboreal and first part of the Late Preboreal as defined by van Geel *et al.* (1981). The zone can be divided into three sub-zones; 4a, 4b and 4c.
Sub-zone 4a starts with a rise in *Betula* percentages towards values of 80%; *Juniperus* percentages are also relatively high during the beginning of this sub-zone. This sub-zone can be considered equivalent to the Friesland oscillation or phase defined by Behre (1966) and van Geel *et al.* (1981), respectively.
Sub-zone 4b begins with a decrease in arboreal pollen in favour of Gramineae, with Gramineae percentages almost as high as those of *Betula*. The birch forest opened for a short period during this phase. Towards the end of this sub-zone *Populus* percentages increase. Sub-zone 4b can be considered equivalent to the Rammelbeek phase as defined by van Geel *et al.* (1981).

Sub-zone 4c begins with a prolonged rise in *Betula* percentage towards values as high as 80%. The percentages of *Populus* are the highest during this sub-zone. *Populus tremula* (aspen) may have been an important forest constituent. As *Populus* is not always recognized, especially in older investigations, its absence in the samples cannot always be interpreted as a real absence in the vegetation.

2.4.6 Zone 5 (9,500 - 9,150 BP)

Zone 5 (*Pinus* PaZ) is characterized by a rise in *Pinus* percentages to values exceeding 80%. Vegetation development continues after this zone with the appearance of *Corylus* around 9,150 BP as the first thermophilous species from the Holocene closed deciduous forest. Although this zone is beyond the scope of the present investigation, it is used here because it is a clear marker in the biostratigraphic record. Zone 5 can be considered equivalent to the first part of the Boreal zone, as defined by Behre (1966), or the latter part of the Late Preboreal zone as defined by van Geel *et al.* (1981).

2.5 Difficulties in the interpretation of palynological records

2.5.1 Pollen-vegetation relationship

The relationship between the pollen record and the corresponding vegetation depends strongly on differences in pollen production, transport and preservation. With the interpretation of palynological records, one has to be aware of this complex relationship. Nevertheless, the presence of pollen permits conclusions back to the vegetation that produced it (Faegri and Iversen, 1989). For a more exact determination of the pollen-vegetation relationship, recent pollen spectra in combination with vegetation mapping should be applied (see for instance Lichti-Federovich & Ritchie, 1968). According to Janssen (1981), any attempt to reconstruct past vegetation by means of pollen analysis must be preceded by an effort to separate the allochthonous element from the autochthonous element. Therefore, regional and local pollen deposition, over-representation, ecology, reworking and determination level are considered in the interpretation of the palynological signals. The Lateglacial vegetation as described in this study should be considered as the result of the interpretation of pollen records.

2.5.2 Trees and shrubs

Shrubs were present in The Netherlands since the beginning of the Lateglacial, *Salix* and *Betula nana* scrub was presumably present already at the end of the Pleniglacial. *Hippophaë rhamnoides* and *Juniperus communis* scrub developed during the first part of the Lateglacial. The first *Betula* and *Salix* trees are supposed to have appeared in the Bølling period. With the passing of the tree-limit over The Netherlands, arboreal pollen deposition increased substantially. The distinction between shrub and tree species of *Betula* and *Salix* is therefore important, as it would have strongly influenced the AP component in the total pollen deposition.

Birch

The *Betula* pollen record from the Lateglacial and Early Holocene is considered to be derived from predominantly tree birches. Nevertheless, birch shrubs (*Betula nana*) possibly formed a major contribution to the *Betula* pollen percentage during the earliest phase of the Lateglacial. Macro remains from *Betula nana* have frequently been found in Lateglacial deposits, but palynologically *Betula nana* is difficult to separate from other *Betula* pollen. The species contributing to the *Betula* pollen type are *B. nana*, *B. pendula* and *B. pubescens*, subdivided in subspecies *B. pubescens* ssp. *pubescens* and *B. pubescens* ssp. *tortuosa*. Some authors have made a division between a *Betula pendula/pubescens-type* and a *Betula nana*-type, based on differences in the pore and polar diameter of the pollen grain according to Terasmaë (1951), Birks (1968), Usinger (1975) and van Leeuwaarden (1982). For The Netherlands, the *Betula nana* pollen-type has been distinguished only in a few pollen diagrams. In the mosslayer at the base of the Gulickshof organic deposits (Hoek *et al.*, 1997) remains of *Betula nana* leaves are common. The results from the pollen analysis show a herbaceous vegetation with *Betula nana*-type in low percentages. Van Dinter and Birks (1996) demonstrated that in some cases the presence of abundant *Betula* tree pollen not nessecarily indicates the presence of *Betula* trees. For The Netherlands, tree birch was present since the Bølling (Bohncke, 1993). The amount of dwarf birch scrubs decreased towards the Holocene, which is indicated by the diminishing contribution of *Betula nana* pollen to the total *Betula* pollen percentage (figure 2.4).

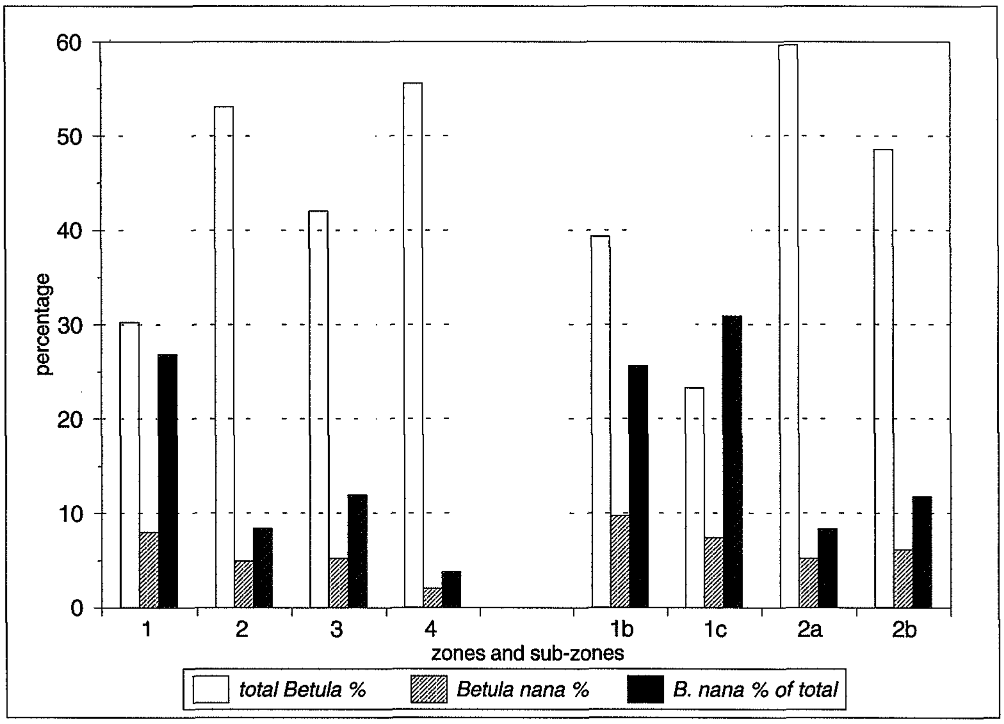

Figure 2.4 The decreasing contribution of *Betula nana* pollen to the total *Betula* pollen percentage per zone and sub-zone.

Willow

Like with *Betula*, the occurrence of *Salix* shrubs during the Lateglacial should not be underestimated. Especially in the earlier part a significant amount of the *Salix* pollen will have been derived from dwarf willows such as *S. herbacea*, *S. polaris* and *S. reticulata*. Unfortunately, a separation between different pollen types was not regularly made in the pollen diagrams in the database. In only a few palynological studies *S. pentandra*-type, *S. glauca*-type, *S. polaris* and *S. herbacea* were distinguished, predominantly based on the pollen keys provided by Erdtman *et al.* (1963) and Faegri and Iversen (1975). The presence of pollen from the chionophilous *S. polaris*, *S. reticulata* and *S. herbacea* is mainly restricted to the earlier part of the Lateglacial, where conditions were favourable for these species. The pollen taxa within the genus *Salix* have not been considered separately in this study and were combined as *Salix*.

2.5.3 Parallel vegetation development

Problems of parallel vegetation development can arise in many cases of pollen records from incomplete sections with respect to the biostratigraphical position of pollen assemblages. The assemblages assigned to zone 2 (Allerød) and 4-5 (Preboreal) can be very similar. Further, the vegetation development from zone 4 to 5 is similar to that from sub-zone 2a to 2b – high *Betula* percentages followed by high *Pinus* percentages. Additional palynological and sedimentological indications are essential to distinguish between these zones and sub-zones.

The progressive vegetation development in zone 2 was interrupted by the Late Dryas climatic revertance. This indicates that if a more herbaceous vegetation follows the zone dominated by *Pinus*, the latter can be attributed to zone 2. The presence or absence of *Corylus* is not simply the key, as it is often present in zone 3 with or without other thermophilous tree pollen as a result of reworking during the Late Dryas. In the case of a zone dominated by *Pinus* succeeded by a rise in *Corylus* and subsequently by other deciduous trees, the *Pinus* dominated zone can be attributed to zone 5. Again, the presence of *Thelypteris palustris* spores in high percentages indicates a characterization as zones 4 or 5 rather than 2. *Thelypteris palustris* is a thermophilous fern and has a present day distribution in Scandinavia similar to that for *Corylus avellana* (Mossberg *et al.*, 1992).

A more delicate problem is the distinction between the regressive vegetation development from sub-zone 1b to sub-zone 1c and sub-zone 2a1 to sub-zone 2a2. As the sub-division of the Allerød *Betula* phase, as described in the previous section, has not often been made, the low within Allerød *Betula* curve, characteristic for sub-zone 2a2, has frequently been interpreted as Earlier Dryas (sub-zone 1c). The first *Betula* peak has in those cases been interpreted as Bølling (sub-zone 1b). However, the presence of *Juniperus* and *Salix* peaks, together with high values for heliophilous taxa like *Hippophaë* and *Helianthemum* are indicative for sub-zone 1c, whereas these taxa have low values in sub-zone 2a2.
Vegetation succession can be considered to be more or less continuous in time if sediments do not show indications of hiatuses. Finally, the relative position in the profile of aeolian sediments, which most likely must have been deposited during the Late Dryas, gives an indication of relative age.

2.5.4 Lateglacial human influence

Human influence on the vegetation is large since the middle of the Holocene. For the Lateglacial, however, the influence of man on vegetation is considered to be of minor importance. Stapert (1986) described the presence of Late Paleolithic hunters belonging to the Hamburg culture in the northern Netherlands. A radiocarbon date from burned *Salix* brushwood in a possible camp-site gave an age of 11,540 ± 270 BP. Van der Hammen (1951) and Hijzeler (1957) described the so-called Usselo culture, human occupation during the late Allerød in The Netherlands. The Usselo layer, associated with the Usselo culture is a wide-spread organic layer frequently containing charcoal particles, mainly consisting of *Pinus*. Forest fires must have occurred frequently, which can be recognized in the presence of charcoal and a decrease in AP percentage in favour of herbs and a greater frequency of Chenopodiaceae and *Epilobium angustifolium* (van der Hammen, 1951, 1957). Within the Usselo layer flints have been found frequently which are ascribed to the Late Palaeolithic Tjonger or Federmesser culture (van den Toorn, 1967). Radiocarbon ages obtained from charcoal of the Usselo layer centers around 11,000 BP, ranging from 11,440 ± 120 BP to 10,365 ± 200 BP (see chapter 3). The extent of human influence on vegetation has been investigated by Bos and Janssen (1996) for a Late Palaeolithic Federmesser site near Milheeze, southern Netherlands. They showed that repeated burning of the (open) *Pinus* forest can be detected by pollen analysis. The distance over which the pollen evidence was recorded was very small, less than 150 m. It is clear that man had some influence on the vegetation, but the impact can only be seen relatively near to camp-sites.

2.5.5 Lateglacial fauna

The influence of animals on the Lateglacial vegetation is still unknown. Grazing by reindeer will have influenced vegetation composition particularly during the periods when more open vegetation types occurred. Direct indications (radiocarbon dated bones) for the presence of reindeer during the Lateglacial are known from Germany and Belgium but not from The Netherlands (Lanting and van der Plicht, 1995). The presence of Late Palaeolithic camp-sites indirectly points to the presence of reindeer. As reindeer lost their habitat during the course of the Lateglacial, their influence on the vegetation might have decreased.
The role of birds in the distribution of plants is important (Gillham, 1970). Bird migration will have favoured the fast migration of species like *Hippophaë rhamnoides*, *Juniperus communis* and aquatics.

2.6 Comparison with biostratigraphies from adjacent regions

Regional syntheses concerning vegetation history in the neighbouring countries have been presented within the North Atlantic Seaboard Programme (**NASP**) by Berglund *et al.* (1994) and Walker *et al.* (1994). The regional syntheses compiled by Berglund *et al.* (1996) only present some key-diagrams from IGCP regions. For direct comparison with the vegetation development in The Netherlands, palynological records from northern Belgium and the western part of Germany have been used. The vegetation development in Schleswig-Holstein (northern Germany) and Denmark is also largely comparable to that in The Netherlands but regarding the distance of a several hundred kilometers a time lag might be assumed (see also Paus, 1995).

2.6.1 Northern Belgium

In Belgium, many pollen diagrams have been published in the last decades providing a good spatial resolution (Paulissen and Munaut, 1969; Munaut and Paulissen, 1973; Vanhoorne and Verbruggen, 1975). Especially the western part of sandy Flanders is well investigated by Verbruggen (1971, 1979) and these data have been included in the database. In her dissertation, le Maire-Heyvaert (1983) gave a compilation of the Belgian pollen diagrams. The pollen diagrams dated by means of radiocarbon from the northern part of Belgium have been used for reconstruction of the regional vegetation development in time (see chapter 3).
The biostratigraphic sub-division in Belgium (Verbruggen, 1979; Verbruggen *et al.*, 1996) is in general comparable to that in The Netherlands.

2.6.2 North-western Germany

For adjacent parts of Germany the amount of data is sparse, a score of high quality diagrams from Schleswig-Holstein are available (Usinger, 1975, 1981, 1982) but more to the south, Lateglacial pollen diagrams are scarce. Because the high quality sites from Usinger from Schleswig-Holstein are out of spatial range, only a limited number of diagrams from Germany have been used for reconstruction of the regional vegetation development in time; Averdieck and Dobling (1959), Rehagen (1964) and Behre (1966). Recently, some palynological records from Ost-Friesland have been published that contribute to the vegetation history of this region (Mecke, 1995; Freund, 1995). Unfortunately, only a few pollen diagrams in the adjacent part of Germany have radiocarbon time-control.

For northern Germany, however, discrepancies occur in the biostratigraphical terminology for particularly the earliest part of the Lateglacial in relation to that of The Netherlands. The comparison is therefore completely dependent on the occurrence of biostratigraphical markers. If the biostratigraphical interpretation by the original authors is ignored, the pollen diagrams appear to be largely comparable to those in The Netherlands as will be discussed below.

2.7 **Discussion** (together with W.H. Zagwijn)

Regional trends in vegetation development can be recognized in pollen diagrams from different landscape types, these trends are considered to be synchronous over The Netherlands. The biostratigraphy of the Lateglacial in northern Belgium closely resembles that of The Netherlands. It appears that the sub-division in the regional vegetation development in The Netherlands can also be compared to pollen diagrams in Germany. There are, however, problems that can be regarded as inconsistencies in stratigraphic definition. The sub-division of the Allerød *Betula* phase (sub-zone 2a in the present study) seems to be essential for understanding of the problems that have arisen in the biostratigraphical sub-division and nomenclature of the earliest part of the Lateglacial. The inconsistencies in nomenclature of the earlier part of the Lateglacial in the two areas can be read from table 2.2.

Table 2.2 Comparison between the biostratigraphical sub-division in The Netherlands and parts of north-western Germany.

age BP	**Biostratigraphy Netherlands (Hoek, 1997)**		**Biostratigraphy north-western Germany (Menke, 1985; Behre, 1996)**	
9,150				
	5	Late Preboreal	Boreal	
9,500				
	4c		Präboreal c	
9,750				
	4b	Early Preboreal	Präboreal b	
9,950				
	4a		Präboreal a	
10,150				
	3b			
10,550		Late Dryas	Jüngere Dryas	
	3a			
10,950				
	2b		Alleröd	
11,250				
	2a2	Allerød		
			Mitteler Dryas	
11,500				
	2a1		Bölling	
11,900				
	1c	Earlier Dryas	Älteste Dryas	
12,100				
	1b	Bølling		
12,450			Meiendorf	
	1a	Earliest Dryas		
12,900				*Artemisia* rise
	LP	Late Pleniglacial	Pleniglazial	

The discrepancy is mainly the result of a difference of opinion about the correlation with the section at Bølling Sø, first studied by Iversen (1949).
In this study, Iversen described the so-called Bølling oscillation, below beds atrributed to Allerød. It was characterized by an increase of *Betula* pollen (including tree birches) within a zone with a pollen assemblage comprising *Hippophaë*, *Helianthemum*, *Artemisia*, and some others considered characteristic for Older Dryas (Zone I). Therefore, the Bølling interval was labelled as Ib. It is separated from Allerød (Zone II) by a herb peak (sub-zone Ic), as defined by Iversen (1954). Figure 2.5 shows the pollen diagram from Bølling-Sø redrawn after Iversen (1973) a clear dip in the *Betula* curve can be seen which separates the Bølling (Ib) and Allerød oscillation.

In The Netherlands, van der Hammen (1949, 1951) also found a very similar sequence (see figure 2.1), showing a peak of *Betula* (including tree birches) in a zone with *Hippophaë*, *Helianthemum*, and *Artemisia*. He correlated this interval with (Iversen's) Bølling oscillation.

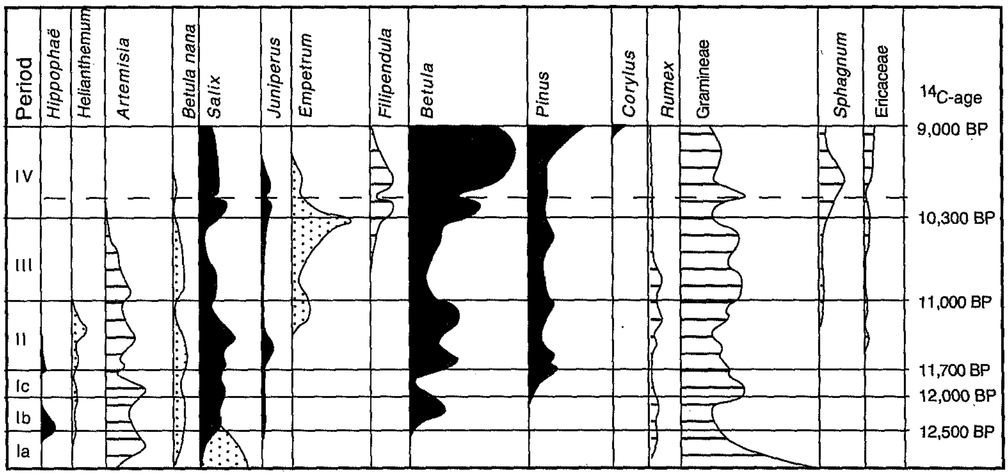

Figure 2.5 Pollen diagram Bølling-Sø (modified after Iversen, 1973).

In north-western Germany, also correlations with Iversen's Bølling were made since Schüttrumpf (1955) found at various sites on top of a zone with high values of *Hippophaë* a maximum of tree birches. This maximum was correlated with Bølling. This birch maximum is followed by a weak decline which is in turn followed by another rise, which according to Schüttrumpf belongs to the beginning of Allerød. Menke (1968) and Usinger (1981, 1985) found essentially the same features. Menke first indicated that below the rise in tree birches, a zone can be found with dwarf birch (*Betula nana*), which also shows an oscillation which he eventually defined as Meiendorf Interstadial (Menke in Bock *et al.*, 1985).
Usinger (1985) showed that in Schleswig Holstein several more or less pronounced Betula maxima are present in the Allerød interval and he concluded that the first of them should be correlated with Iversen's Bølling at Bølling Sø. If this correlation is correct, then Bølling forms part of Allerød in its original definition. Usinger, however, in his further discussion used still the term Bölling-pollenzone for the pre-Allerød oscillation in The Netherlands and elsewhere. Menke (in Bock *et al.*, 1985) in defining the Meiendorf Interstadial, accepted Usinger's correlation, but decided to maintain the name Bölling for the interval of the first tree birch maximum, instead of including it in the Allerød.

All this has resulted in considerable confusion. In fact the problem comes down to the precise correlation of the sites from The Netherlands and north-western Germany with the site of Bølling Sø. Two possibilities exist:

1 The correlation by van der Hammen (1949, 1951) is correct. In that case the earliest *Betula* maximum of the Lateglacial should be referred to as Bølling.
2 The correlation by Usinger (1985) is correct. In that case the name Bølling should be disregarded completely. As the sequence called Bølling at the type-site forms part of Allerød, this latter name has priority. The oscillation below Allerød then should be called Meiendorf.

No relevant radiocarbon dates of the type-Bølling sediments, which could solve the problem, are available. Stockmarr (1974) published data from a site 1.5 km distant from Bølling Sø, which came however from Allerød beds.
Radiocarbon dates of the end of Meiendorf Interstadial in Lith/Elmshorn yielded 12,010 ± 75 BP (Menke in Bock *et al.*, 1985). Recently, Litt (1994) discussed the presence of the Meiendorf Interstadial in the palynological record of Krumpa. A radiocarbon date of overlying deposits referred to as Bölling gave an age of 11,770 ± 110 BP, which coincides with sub-zone 2a1 of the present study. Neither Usinger nor Menke made use of radiocarbon dating in their discussions. Therefore, a further evaluation of the matter can be only made on the weight of the palynological arguments or by new radiocarbon datings, particularly at the Bølling type-site.
In a separate study, a more detailed discussion of palynological correlations will be presented (Hoek and Zagwijn, in prep.). For the time being it is preferred to maintain the original correlation by van der Hammen (1949) and therefore to consider Meiendorf as a later synonym of Bølling interstadial. In any case it can be concluded that there is no case to quote a Meiendorf Interstadial as the earliest evidence for warming before 13,000 BP (see for instance Walker, 1995).

3 LATEGLACIAL AND EARLY HOLOCENE CLIMATIC OSCILLATIONS AND CHRONOLOGY OF THE VEGETATION DEVELOPMENT IN THE NETHERLANDS

3.1 Introduction

The Weichselian Lateglacial marks the transition between the cold Weichselian Late Pleniglacial and the warmer Holocene; the Lateglacial or Late Weichselian chronozone is dated between 13,000 and 10,000 BP according to Mangerud *et al.* (1974).
Within the framework of **IGCP-158B** – *Palaeohydrological Changes in the Temperate Zone in the Last 15,000 Years* – regional syntheses of palaeoecological events have been compiled for **IGCP** type-regions in Europe (Berglund *et al.*, 1996). The project **IGCP-253** – *Termination of the Pleistocene* – and especially its sub-project – *North Atlantic Seaboard Programme* (**NASP**) – has been concerned with the history of environmental changes in areas adjacent to the North Atlantic during the last glacial-interglacial transition (Lowe, 1994). Regional syntheses of environmental changes have been compiled for the Weichselian Lateglacial within this programme (Lowe *et al.*, 1994, 1995; Walker *et al.*, 1994 and Walker, 1995). This study supplements the contribution to these projects by Bohncke (1993) who presented selected Lateglacial pollen diagrams from The Netherlands. Special emphasis in the present study is given to radiocarbon chronology of the vegetation development on the basis of a large data set from The Netherlands and neighbouring countries. The well established chronological framework facilitates comparison with other well dated palaeoclimatic records.
The ^{14}C calibration curve based on tree-ring chronologies has until now not been extended to this time-interval (Becker and Kromer, 1993; Kromer *et al.*, 1996). Although ^{14}C calibration based on U-Th series does extend into the Lateglacial (Bard *et al.*, 1993), this calibration does not have the accuracy provided by the dendro-curve. The identification of at least one ^{14}C plateau within the Lateglacial (Ammann and Lotter, 1989; Wohlfarth, 1996) emphasizes the inaccuracy when using this extended ^{14}C calibration for the Lateglacial. Radiocarbon dates presented in this paper are therefore given as uncalibrated ^{14}C years BP.

Table 3.1 Chronostratigraphy of the Lateglacial (van Geel *et al.* 1989) or Late Weichselian (Mangerud *et al.*, 1974)

Zones (van Geel *et al.*, 1989)				Chronozones (Mangerud *et al.*, 1974)	
HOLOCENE				FLANDRIAN	
....			10,150 ± 50	....	10,000
III	Late Dryas			Younger Dryas	
....			10,950 ± 50	....	11,000
II	Allerød			Allerød	
....			11,900 ± 50	....	11,800
Ic	Earlier Dryas			Older Dryas	
....			12,150 ± 100	....	12,000
Ib		Bølling *s.s.*			
	Bølling *s.l.*	....	12,400 ± 100	Bølling	
Ia		Earliest Dryas			
....		......	12,930 ± 210	....	13,000
PLENIGLACIAL				MIDDLE WEICHSELIAN	

In this paper biostratigraphical terminology is followed when considering subdivision on biological grounds. Unfortunately the terminology that was originally developed for biostratigraphical zones (Bølling, Allerød *etc.*) has been used frequently in a chronostratigraphic sense (see also Walker, 1995). Chronostratigraphy of the Lateglacial according to van Geel *et al.* (1989) and Mangerud *et al.* (1974) are presented for comparison in Table 3.1. To avoid confusion that can easily arise with the established bio- and chronostratigraphical terminology, vegetation development in this paper is considered in a chronological context.

It is generally acknowledged that the analysis of palaeovegetation can be used for reconstructing palaeoclimate. However, a clearer distinction is required between climatic and other environmental abiotic agents affecting vegetation development. Palynology is a common tool for reconstructing vegetation development. Most reconstructions are based on a single pollen diagram; pollen diagrams from different locations covering the same time interval often show clear variations in local vegetation development caused by local influences. On the other hand, regional vegetation development can be reconstructed using a palaeogeographical approach. Based on many point observations in a relatively small region, vegetation patterns and their relation with the abiotic landscape can be reconstructed. Common trends in vegetation development may reflect regional synchronous responses of the vegetation caused by changes in climate, as discussed in this study. Local variations between the point observations reflect spatial variations in the abiotic landscape (Hoek, 1997).

3.1.1 Climatic oscillations

During the Lateglacial and Early Holocene at least four episodes of climatic deterioration have occurred since the major climatic amelioration of 13,000 BP; these can be recognized in the oxygen isotope records from the Greenland Ice-cores (Johnsen *et al.*, 1992; Grootes *et al.*, 1993). Terrestrial, radiocarbon dated climatic deteriorations registered on the Swiss Plateau are described by Eicher and Siegenthaler (1976) and in more detail by Lotter *et al.* (1992); these are recorded mainly from oxygen-isotopes and slightly using palynology. The Aegelsee-oscillation, starting shortly before 12,000 BP and the Gerzensee-oscillation, shortly before 11,000 BP are minor fluctuations. The Younger Dryas oscillation starting around 11,000 BP is the most pronounced climatic deterioration recorded by oxygen-isotopes. In the Early Preboreal the Preboreal oscillation has been recorded around 9,500 BP, though only by oxygen-isotopes. Atkinson *et al.* (1987) recognized oscillations in the Lateglacial *Coleoptera* records from Central Britain.

The oxygen-isotope curves from Gerzensee (Lotter *et al.*, 1992) and GRIP (Johnsen *et al.*, 1992) are compared in figure 3.1 with the *Coleoptera* curve (Atkinson *et al.*, 1987), the latter giving an indication for the changes in mean annual temperature during the Lateglacial. The positions of the Aegelsee oscillation (**A**), Gerzensee oscillation (**G**), Preboreal oscillation (**P**) and the Laacher See Tephra (**LST**) are indicated on the Gerzensee curve. The deposition of the Laacher See Tephra that occurred around 11,000 BP (van den Bogaard and Schmincke, 1985) serves as an isochronous time-marker in many Lateglacial sediments. So far, however, no *in situ* volcanic ashes from the Laacher See have been found in The Netherlands.

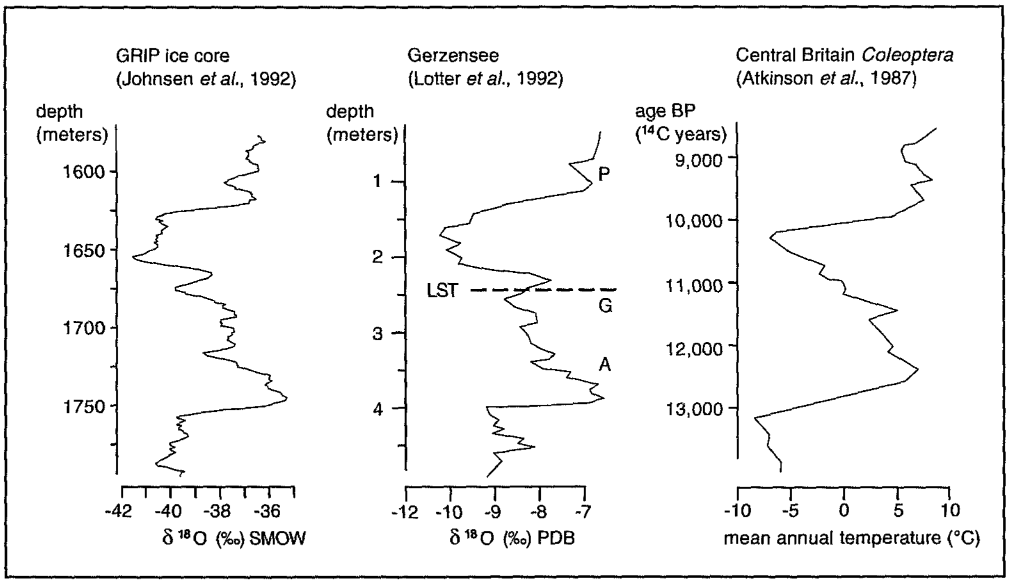

Figure 3.1 Oxygen-isotope curves from the Greenland ice-core GRIP (Johnsen *et al.* 1992) and Gerzensee (Lotter *et al.* 1992) compared with the temperature curve based on fossil Coleoptera from Central Britain (Atkinson *et al.* 1987).
P=Preboreal oscillation, LST=Laacher See Tephra, G=Gerzensee oscillation, A=Aegelsee oscillation.

Palaeoclimatic indicators such as oxygen-isotopes and *Coleoptera* have rarely been investigated in The Netherlands; in Usselo I (van Geel *et al.*, 1989) and Notsel (Bohncke *et al.*, 1987) palaeotemperature records were constructed based on fossil *Coleoptera*. According to these records climatic amelioration started around 13,000 BP. However, the records do not show the clear oscillations within the Lateglacial described by Atkinson *et al.* (1987) for Britain and Coope and Lemdahl (1995) for northern Europe.

Climatic reconstructions for the Lateglacial in The Netherlands are mainly based on palaeobotanical evidence (van Geel *et al.*, 1989; Bohncke, 1993; Walker *et al.*, 1994). A comparison with independantly obtained palaeoclimate data from this area is therefore not yet feasible. Accordingly, in this study only a qualitative comparison is made between the palaeoclimate signal derived from oxygen-isotopes and the regional vegetation development in The Netherlands.

3.1.2 General vegetation development

Syntheses of environmental changes during the Lateglacial have been constructed within the North Atlantic Seaboard Programme (**NASP**). Reconstruction of changes in vegetation in this region was an important aim of this programme. Regional syntheses concerning vegetation history in The Netherlands and neighbouring countries have been presented by Bohncke (1993), Berglund *et al.* (1993) and Walker *et al.* (1994).
Considering the Lateglacial, especially in The Netherlands, the following general vegetation development has been described by various authors (e.g. van der Hammen, 1951; van Geel *et al.* 1989; Bohncke, 1993).
According to these authors, a sparse vegetation cover existed at the end of the Weichselian Late Pleniglacial comprising Gramineae, Cyperaceae and some dwarf shrubs, while many places were altogether bare. From around 12,900 years BP species-rich herbaceous plant communities and dwarf bushes developed as a result of a rise in temperature; scattered *Betula* trees were present in the open vegetation type. In the Allerød interstadial starting around 11,900 years BP, rather open *Betula* and *Pinus* woods dominated and the so called Usselo soil with charcoal particles was formed. The development to a more dense vegetation cover was interrupted by the colder Late Dryas stadial at 10,950 years BP, when the area of *Pinus* woods contracted considerably in favour of herbaceous plant communities. At the start of the Holocene around 10,150 years BP *Betula* woods and later *Pinus* woods again developed as a result of temperature rise. The present study emphasizes also on smaller climatic fluctuations within the Lateglacial and Early Holocene.

Some aspects of vegetation development during the Weichselian Lateglacial in The Netherlands remain unexplained and can possibly be ascribed to local variations in lithology, geomorphology and hydrology (Hoek, 1997). Pollen diagrams from different areas, embracing the same time-stratigraphical interval, often show clear variations in vegetation history which cannot be explained on climatological grounds alone. For example, reference is made to Watts (1980) who has discussed these regional vegetation variations during the Lateglacial in Europe.

3.1.3 Study area

Over 400 palynological records have been investigated in The Netherlands by several institutes over the last decades, covering part or whole of the Weichselian Lateglacial. Locations of the palynologically investigated sections are shown in figure 2.3. Radiocarbon dated pollen diagrams from northern Belgium and western Germany are also used for the establishment of the vegetation chronology.
It might be expected that in The Netherlands there would be only minor spatial differences in climate during the Weichselian Lateglacial due to the small area and relatively large distance to the former coastline (see figure 2.2). As sea-level was between 65 and 90 meters below present level (Jelgersma, 1979), the coastline was more than 200 kilometers distant and any substantial climate gradient induced by the sea can be neglected within the country during this period. Regional vegetation development in The Netherlands, as far as it was climatically induced, could be expected to be approximately synchronous, as the maximum distance between datapoints in the north and south is only 250 kilometers.

3.2 Methods

3.2.1 Pollen diagrams

The palynological data from records used in this study were entered directly from the counting sheets into a database. By now over 250 of these sections are available in digital format. In figure 2.3 the pollen diagrams inserted into the database are presented in black, the others by open symbols.
This dense pattern of Lateglacial, palynologically investigated locations is used to reconstruct vegetation patterns for different time-windows during the Lateglacial (Hoek, 1997).
For the construction of pollen diagrams a uniform pollen sum was used to calculate percentages, thus providing diagrams that facilitate comparison. In this pollen sum only Lateglacial trees, shrubs and dry herbs are included, i.e. the group of regional taxa according to Janssen (1973). The local pollen taxa, aquatics and riparian herbs including Cyperaceae, as well as spores and thermophilous trees, were excluded from the pollen sum. Major shifts in the main pollen taxa, radiocarbon dated in several pollen diagrams distributed over The Netherlands, are used to construct a regional zonation. After establishing a regional biostratigraphy a regional chronological framework is constructed with the help of radiocarbon dates.

3.2.2 Zonation

Only those taxa that determine the vegetation aspect and may reflect regional trends are used for biostratigraphical zonation of the diagrams. Janssen (1980) has discussed different stratigraphical zonation concepts for the division of pollen diagrams. Biostratigraphy is used as a tool for the reconstruction of patterns in time and space. The bio-zones described here sometimes differ from those given by the original authors, who were at that time not able to use many locations for regional comparison and often used different pollen sums.
Most important in the zonation are the fluctuations in *Betula* and *Pinus* percentages. Shifts in the percentages of Arboreal Pollen (AP), Non Arboreal Pollen (NAP), *Salix*, *Juniperus*, *Populus*, *Artemisia* and *Empetrum* were also used for the zonation.
Other non-palynological stratigraphical marker-horizons have additionally been considered in the zonation. For instance, the presence of a thick layer of characteristic coversands of Late Dryas age overlying organic deposits gives a relative age for those deposits – older than Late Dryas.

3.2.3 Radiocarbon dates

In order to establish a regional chronological framework, the zonation scheme was attached to the radiocarbon time-scale based on available radiocarbon dated diagrams. Although most published diagrams have only few dates, together with dates from other diagrams a reasonably large radiocarbon dataset was compiled. Radiocarbon dates for the period under investigation from The Netherlands, northern Belgium and the western part of Germany are given in *appendices 3A & 3B*; the Groningen dates published before 1961 were corrected according to Vogel and Waterbolk (1963). Van Geel *et al.* (1989) presented

a stratigraphic sub-division for the Lateglacial (Table 3.1) based on the palynological type section at Usselo, from which a large number of radiocarbon dates are available. For the early Holocene, Behre (1966, 1967, 1978) and van Geel *et al.* (1981) presented sub-divisions for the sections at Westrhauderfehn and De Borchert, respectively. The sub-division proposed here happens to be essentially comparable with those proposed by them but is extended from a local to a regional scale and is also refined in time-resolution.
A biostratigraphical zone code could be assigned to the 239 radiocarbon dated samples derived from 102 pollen diagrams.
In *appendices 3A & 3B* the radiocarbon ages are followed by the numerical zone codes used in the database; and then indicate the assigned biostratigraphical zone or sub-zone according to Table 2.1. Additional characters are used to indicate whether the top (**T**), base (**B**) or undifferentiated level (**U**) of the zone was dated. Törnqvist *et al.* (1992) showed that bulk samples from gyttjas and strongly clayey samples can yield ^{14}C ages of up to 600 years older than AMS terrestrial macrofossil samples. Also, AMS-datings from aquatic plants can give ages which exceed those from terrestrial macrofossils, which may be ascribed to the hardwater effect. Therefore, only dates from peat and AMS-datings from terrestrial macrofossils were used for the zonation scheme.
A total of 23 radiocarbon datings from charcoal (mainly *Pinus*-wood) from the Allerød dated Usselo-layer are presented in Table 3.2. De Vries *et al.* (1958), Zagwijn (1962) and Lanting and Mook (1977) have earlier reviewed some of these data.

Table 3.2 Radiocarbon dates from charcoal (mainly *Pinus*-wood) from the Usselo-layer (n=23).

Site name	nr.	age	±	reference
Budel II	GrN-1675	11,440	120	Lanting and Mook (1977)
Deelen	GrN-909	11,265	120	de Vries *et al.* (1958), Lanting and Mook (1977)
Lemele	GrN-647	11,230	400	de Vries *et al.* (1958), Lanting and Mook (1977)
Bentheim	GrN-11531	11,200	140	Schwan (1988)
Horn-Haelen	GrN-7297	11,200	100	Lanting and Mook (1977)
Duurswoude I (Waskemeer)	GrN-4871	11,150	190	Lanting and Mook (1977)
Duurswoude II	GrN-1565	11,090	90	Lanting and Mook (1977)
Budel IV	GrN-1687	11,070	90	Lanting and Mook (1977)
Nordlohne	GrN-10082	11,040	410	Schwan (1987)
Nordlohne	GrN-10083	11,040	280	Schwan (1987)
Geldrop I / Tjonger	GrN-603	11,020	230	de Vries *et al.* (1958), Lanting and Mook (1977)
Uchelen Goudvink	GrN-907	11,010	120	de Vries *et al.* (1958), Lanting and Mook (1977)
Horn-Haelen	GrN-497	11,000	320	de Vries *et al.* (1958), Lanting and Mook (1977)
Geldrop I / Ahrensburg	GrN-1059	10,960	85	de Vries *et al.* (1958), Lanting and Mook (1977)
Horn-Haelen	GrN-498	10,950	300	de Vries *et al.* (1958), Lanting and Mook (1977)
Nordlohne	GrN-10075	10,910	100	Schwan (1987)
Hilversum Crailose brug	GrN-920	10,900	90	de Vries *et al.* (1958), Lanting and Mook (1977)
Milheeze	GrN-2314	10,880	125	Lanting and Mook (1977)
Milheeze	GrN-16508	10,810	60	Bos and Janssen (1996)
Duurswoude I / Waskemeer	GrN-607	10,800	250	de Vries *et al.* (1958), Lanting and Mook (1977)
Uchelen Goudvink	GrN-937	10,795	130	de Vries *et al.* (1958), Lanting and Mook (1977)
Ermelo	GrN-2500	10,680	240	Lanting and Mook (1977)
Velsen	GrN-646	10,365	200	de Vries *et al.* (1958), Lanting and Mook (1977)

3.2.4 Zone boundaries

^{14}C intensity curves have been constructed to position the zone boundaries on the radiocarbon time-scale. Roeleveld (1974), Berendsen (1984) and Törnqvist (1993) used such curves for dating the beginning and end of peat formation in the coastal environment, or beginning and end of fluvial activity. The curves were constructed using the CalHis 1.0 Program (Stolk *et al.* 1994). In the curve every radiocarbon date is represented by a Gaussian distribution of equal area, the height of each Gaussian distribution being dependent on the error associated with each radiocarbon date; a date with a large error produces a flat Gaussian distribution. The distributions were cumulatively positioned on the uncalibrated ^{14}C time-scale, the cumulative height of the distributions being expressed as an intensity on the horizontal axis. The problems of over-representation as a result of the existence of ^{14}C plateaux that can arise by plotting uncalibrated radiocarbon ages in ^{14}C intensity curves cannot be solved by calibrating the ages with the imprecise calibration curve for the Lateglacial.
Assuming a random distribution of samples, Stolk *et al.* (1989) concluded that for statistical significance at least 40 ^{14}C ages per 1,000 ^{14}C years are needed. However, small peaks in ^{14}C histograms that lack statistical significance may well have geological significance (Berendsen, 1984). The statistical approach does not consider specific geological criteria such as the accuracy of ^{14}C ages, association with the event of interest and distribution in time and space (Törnqvist, 1993). Following Berendsen (1984) and Törnqvist (1993), a critical evaluation of the data set reduced the number of samples used in the construction of ^{14}C intensity curves. In this cleaned data set the limited number of dates for specific events has therefore a geological rather than a statistical significance.

3.3 Results

3.3.1 Regional biostratigraphy

The following regional Pollen-assemblage zones can be distinguished in The Netherlands for the Lateglacial and Early Holocene (chapter 2).
Some of these zones can be divided into sub-zones at different levels of biostratigraphic resolution. In the database numerical codes at three levels indicate the division into zones and sub-zones.

LP NAP Pollen-assemblage Zone (Late Pleniglacial)
1 *Betula-Salix* Pollen-assemblage Zone (Early Dryas *s.l.*)
2 *Betula-Pinus* Pollen-assemblage Zone (Allerød)
3 NAP-*Empetrum* Pollen-assemblage Zone (Late Dryas)
4 *Betula* Pollen-assemblage Zone (Early Preboreal)
5 *Pinus* Pollen-assemblage Zone (Late Preboreal)

An outline of the zonation scheme with zone codes and the main palynological characteristics of zones and sub-zones is given in table 2.1. Changes in percentage are presented as arrows, with major changes represented by double arrows.

3.3.2 Vegetation chronology

With the help of 239 radiocarbon dates derived from 102 pollen diagrams from The Netherlands, northern Belgium and north-western Germany, the regional vegetation development has been attached to the uncalibrated radiocarbon time-scale.

134 out of 166 peat and AMS-datings (81 %) are considered to be consistent (*appendix 3A-1*). From the remaining 32 peat datings (*appendix 3B-1*), 10 from samples with rootlets or from humic extract yield ages which are more than 500 years too young. Some of the remaining samples given in *appendix 3B-1* contain considerable amounts of aquatic pollen or algae; a question mark is thus added to the lithology column indicating that the lithology is more likely to be coarse detrital gyttja rather than peat.

Of the 73 radiocarbon dates derived from gyttjas and organic sediments, 30 datings (41 %) support the zonation obtained from peat and AMS-datings (see *appendix 3A-2*), but most gyttja datings are too old (*appendix 3B-2*).

A cumulative ^{14}C intensity curve is given in figure 3.2 for the base and top datings of the different zones and sub-zones given in *appendix 3A*. The basis of the curve in black is formed by dates for the base and top from the zones and sub-zones from 68 conventionally dated peat samples or AMS dates from terrestrial macrofossils (*appendix 3A-1*).

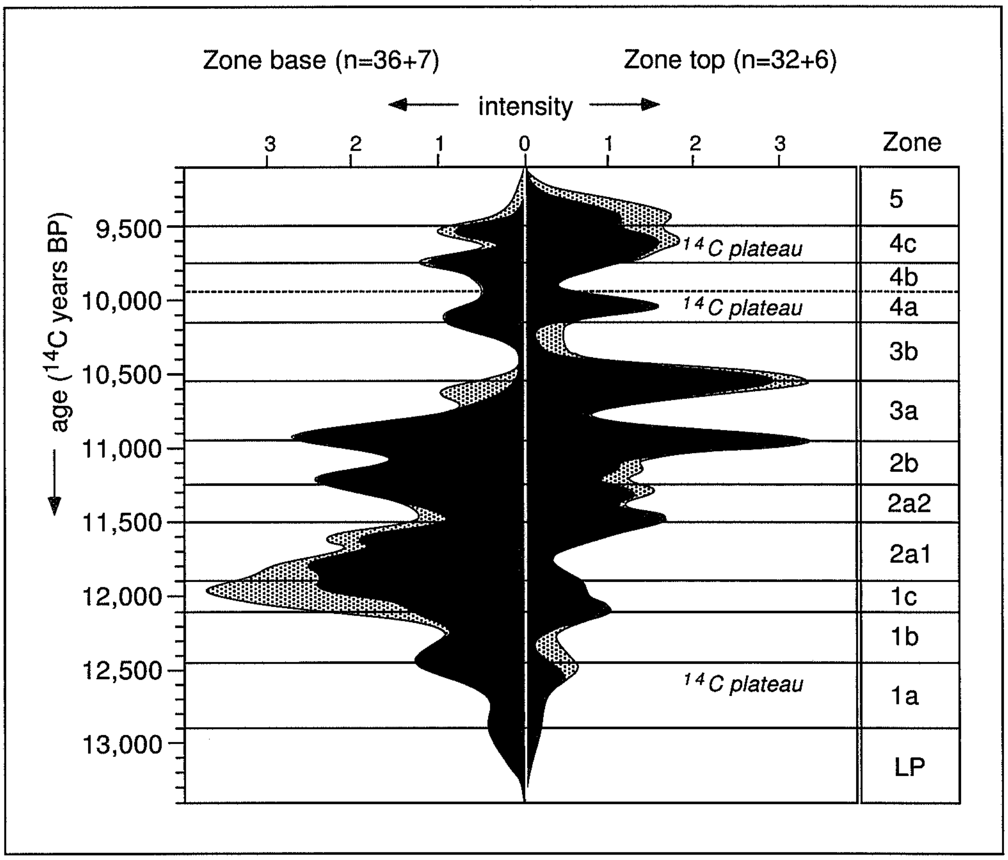

Figure 3.2 Cumulative ^{14}C intensity curve for the zone boundaries, based on top and base datings in *appendix 3A*.

A total of 13 top or base dates in grey from gyttjas and organic sediments which support the zonation scheme (*appendix 3A-2*) were *a posteriori* added to the curve. Peaks in the curves mark the most likely positions for zone boundaries. Ideally the base of each zone should coincide with the top of the preceding zone. In reality this appears to happen in only some cases (see figure 3.2), for example the boundary between zones 2b and 3a. This is mainly a result of the fact that some zones are registered in more mineroclastic sediments than others and therefore fewer dates could be obtained from these zones.
Another factor which can give rise to peaks in the cumulative ^{14}C-intensity curve is the possible occurrence of ^{14}C plateaux. These have been measured as present around 9,600 BP and 10,000 BP based on dendrochronology (Becker and Kromer, 1993), and around 12,700 BP based on AMS dated plant macrofossils from lake sediments (Ammann and Lotter, 1989). Radiocarbon dates with the above mentioned ages tend to occur more frequently and hence may be reflected as peaks in the intensity curve. The positions of the plateaux are shown in figure 3.2 in relation to some smaller peaks in the curve. A stronger clustering can be seen in the early Holocene plateaux around 9,600 BP and 10,000 BP than at the time of the early Lateglacial plateau around 12,700 BP; this may be the result of a lack of early Lateglacial organic deposits.
A total of 157 ages for zones 1-4 given in *appendix 3A* are cumulatively plotted in figure 3.3, followed by a cumulative ^{14}C intensity curve for 23 charcoal datings from the Usselo-layer presented in table 3.2. The number of dates used for each zone are given for the AMS and conventional peat datings from *appendix 3A-1* (dark shaded) and gyttja datings from *appendix 3A-2* (light shaded). Zone boundaries are represented with an error envelope and show positions which correspond with those in figure 3.2.

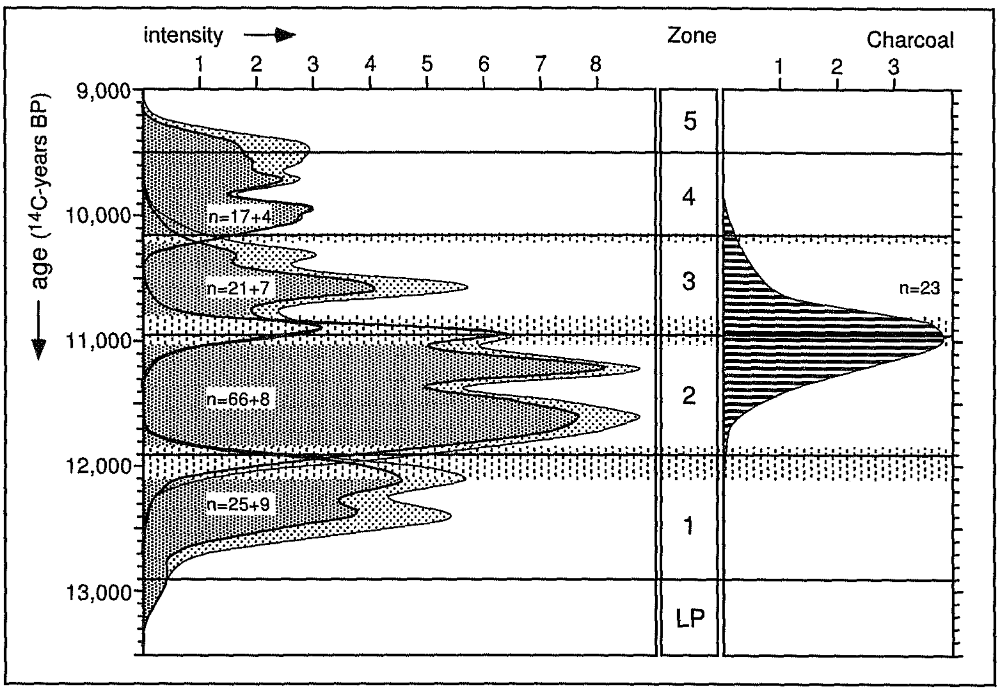

Figure 3.3 Cumulative ^{14}C intensity curve for all accepted dates within each major zone from *appendix 3A* and charcoal datings from table 3.2.

The cumulative ^{14}C intensity curve for 23 charcoal datings from the Usselo-layer presented in figure 3.3 shows ages between 11,300 and 10,700 BP. The peak in this curve is positioned exactly at the boundary between zones 2 and 3 at 10,950 BP. Van der Hammen (1951, 1957) and Polak (1963) postulated that the effect of the Late Dryas cooling caused pine forests to be killed. According to Bohncke *et al.* (1993), however, an increase in wetness at the beginning of the Late Dryas period was the main reason for pine forest demise. Because the dead pine trees were certainly highly susceptible to forest fires, these climate-induced influences might explain the presence of charcoal in the Usselo-layer.

Only a few radiocarbon dates are available for the Late Pleniglacial zone LP (> 12,900 BP). Kolstrup (1980) extracted seeds from a sand and brown loam filled gully near Epe (central Netherlands), palynologically assigned to the Late Pleniglacial. These yielded a radiocarbon date of 14,000 ± 150 BP (GrN-8509). However, because *Potamogeton filiformis* fruits were used, this sample may reflect a hardwater error (Törnqvist *et al.*, 1992) and may therefore be too old. In Lattroperstraat 2 an Upper Pleniglacial organic deposit in a coversand depression was dated by AMS. The date on mosses yielded 12,885 ± 185 BP and woody fragments (possibly root remains) from below this level yielded 12,315 ± 125 BP (Ran, 1990). In Brugge (Belgium) a date of 12,870 ± 230 BP for the end of the Pleniglacial is given by Vandenberghe *et al.* (1974); the top of this zone is therefore set at 12,900 BP.

The base of sub-zone 1a is set at 12,900 BP. In Usselo I the base of this sub-zone coincides with the start of organic accumulation and a rise in *Artemisia* percentage, dated with AMS at 12,930 ± 210 and 12,840 ± 200 (van Geel *et al.*, 1989). Most of the remaining radiocarbon dates from this time-interval are derived from clayey or calcium carbonate rich material and might therefore be too old. The top of sub-zone 1a is positioned at 12,450 BP. Sub-zone 1a can be considered equivalent to the Earliest Dryas zone as defined by van Geel *et al.* (1989).
The radiocarbon age of 12,450 BP for the base of sub-zone 1b, with the first increase in *Betula* percentage, is supported by three dates. The decrease in *Betula* and hence the top of sub-zone 1b is positioned at 12,100 BP. Sub-zone 1b can be considered equivalent to the Bølling zone, Bølling *sensu stricto*, as defined by van Geel *et al.* (1989).
Because deposits from sub-zone 1c are mainly mineroclastic, few reliable radiocarbon dates are available for this sub-zone. This sub-zone is therefore placed between the top of sub-zone 1b at 12,100 BP and the base of the following sub-zone 2a, at 11,900 BP. Sub-zone 1c can be considered equivalent to the Earlier Dryas zone as defined by van Geel *et al.* (1989).

The base of sub-zone 2a, defined by the start of the *Betula* rise, is set at 11,900 BP. This date is supported by more than 10 radiocarbon dates and a large peak in figure 3.2. The boundary between sub-zones 2a1 and 2a2 is set at 11,500 BP. The top of sub-zone 2a1, defined by a slight decrease in *Betula* associated with a slight increase in *Pinus* is dated at 11,500 BP. Fewer dates are available from zone 2a2. The top of sub-zone 2a, immediately before the important rise in *Pinus* percentage, is set at 11,250 BP.
The base of sub-zone 2b, defined by the rise in *Pinus* to values exceeding 20 %, is dated at 11,250 BP. The top of sub-zone 2b, before the decrease in *Pinus* or *Betula*, is dated at 10,950 BP and marked by a sharp peak in figure 3.2. Zone 2 as a whole can be considered equivalent to the Allerød zone as defined by van Geel *et al.* (1989).

The base of sub-zone 3a, marked by a decrease in arboreal pollen percentage, is set at 10,950 BP; in agreement with the date for the top of the preceding sub-zone 2b. The top of sub-zone 3a is dated at 10,550 BP and is represented by a sharp peak in figure 3.2. Because the deposits of sub-zone 3b consist mainly of material rich in mineroclastics, few reliable radiocarbon dates are available for this sub-zone. The base is therefore set at the end of the preceding sub-zone 3a just before the *Empetrum* rise at 10,550 BP and the top at 10,150 BP, coinciding with the *Betula* rise at the base of zone 4. In figure 3.3 the boundary between zones 3 and 4 is positioned between 10,200 and 10,150 BP. Zone 3 as a whole can be considered equivalent to the Late Dryas zone as defined by van Geel *et al.* (1989).

The base of sub-zone 4a, defined by a strong rise in *Betula*, is set at 10,150 BP; the top is positioned at 9,950 BP. This sub-zone can be considered equivalent to the Friesland oscillation or phase defined by Behre (1966) and van Geel *et al.* (1981), respectively.

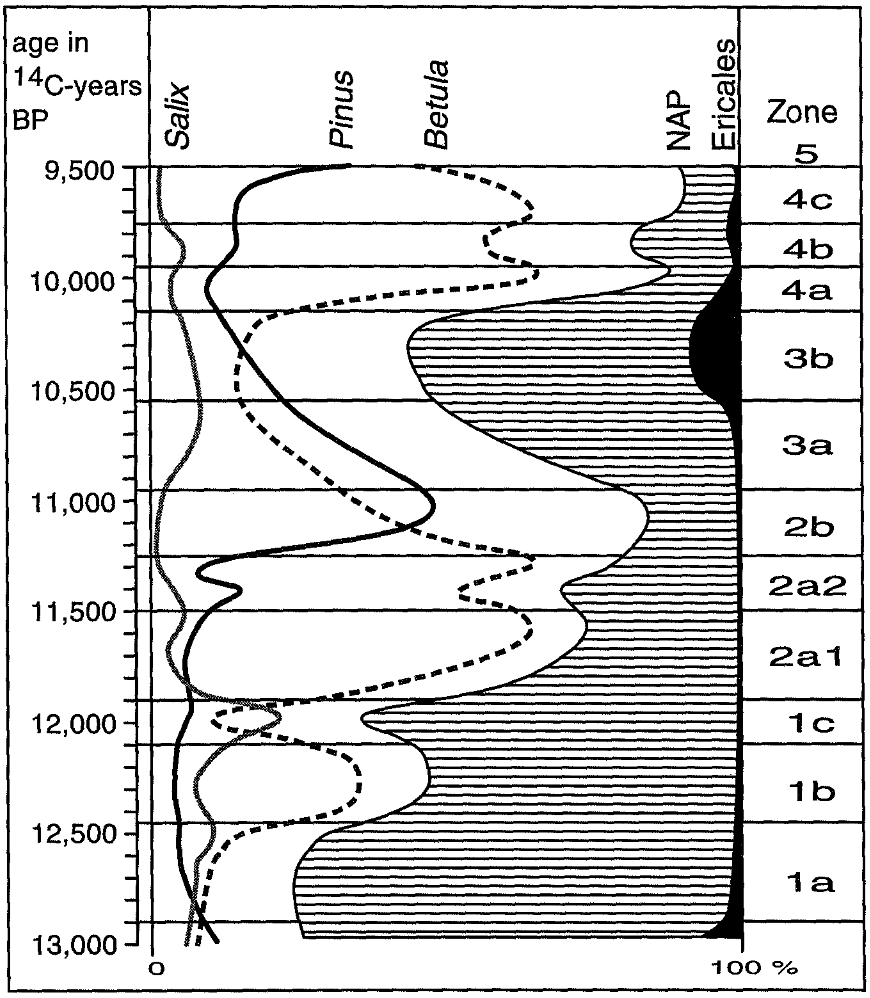

Figure 3.4 Regional Lateglacial and Early Holocene pollen diagram of the main taxa for The Netherlands.

Sub-zone 4b can be recognized in some diagrams and only few dates are available for this sub-zone. The decrease in *Betula* percentage that marks the start of this sub-zone is set at 9,950 BP. Sub-zone 4b can be considered equivalent to the Rammelbeek phase as defined by van Geel *et al.* (1981).
The prolonged rise in the *Betula* curve at the start of sub-zone 4c is set at 9,750 BP; the top of this sub-zone, just before the rise in *Pinus*, is set at 9,500 BP.
Zone 4 as a whole can be considered equivalent to the Preboreal zone, as defined by Behre (1966), or the Early Preboreal and first part of the Late Preboreal as defined by van Geel *et al.* (1981).

The base of zone 5 is set at 9,500 BP. Zone 5 can be considered equivalent to the first part of the Boreal zone, as defined by Behre (1966), or the latter part of the Late Preboreal zone as defined by van Geel *et al.* (1981).

Having established a biostratigraphic and chronological framework, the regional vegetation development with time can now be considered. The regional vegetation development is presented in figure 3.4 as a generalized Lateglacial and Early Holocene pollen diagram for The Netherlands on an uncalibrated radiocarbon time-scale.

3.3.3 Vegetation and climate

The vegetation development is generally considered to have lagged behind the climate signal at the beginning of the Lateglacial. Although the climate was sufficiently warm for woodland, *Juniperus* and *Betula* trees did not respond immediately to climatic amelioration for a variety of reasons (Walker, 1995; Paus, 1995; Walker *et al.*, 1993; van Geel *et al.*, 1989). A progressive development characterized by species immigration will certainly lag behind a climatic amelioration. Walker *et al.* (1993) describe a time-lag of over 500 years in Britain between climate and vegetation for the very early Lateglacial. In southern Sweden, however, vegetation seems to react almost directly to climatic amelioration in the early Lateglacial (Berglund *et al.*, 1994; Coope and Lemdahl, 1995).
Nevertheless, regressive vegetation development caused by a deterioration in climate is considered to be isochronous. The *Pinus* fall around 10,950 BP is therefore considered to be a good time marker. Furthermore, if a species is already present and not subjected to competition or other constraints, it will react almost immediately to climatic change, both in a progressive and regressive direction. For the early Lateglacial the *Artemisia* rise around 12,900 BP is considered to be a reliable palynological indicator for climatic amelioration because it was already present (van der Hammen, 1951; van Geel *et al.*, 1989). *Betula* trees have occured in The Netherlands since at least 12,450 BP. Since then changes in the *Betula* percentage will reflect major climatic changes during the remaining part of the Lateglacial, especially in areas where *Betula* was the dominant arboreal pollen component. The synchronous *Empetrum* rise around 10,550 BP in especially the northern Netherlands may be a result of increased oceanicity, or related to the tolerance of *Empetrum* to active aeolian sedimentation at that time.

The climatic deteriorations recognized from oxygen isotope records from the Greenland ice-cores (Johnsen *et al.*, 1992; Grootes *et al.*, 1993) and the Swiss Plateau (Ammann and Lotter, 1989; Lotter *et al.*, 1992) can be correlated with oscillations based on palynology. For the North Altantic Seaboard Programme this is one of the main issues (Lowe, 1994;

Lowe *et al.*, 1994; Lowe *et al.*, 1995; Walker, 1995). The Lateglacial vegetation development in The Netherlands presented in this paper has the advantage of a well established chronological framework that facilitates comparison with other well dated records, such as oxygen isotope records from the Swiss Plateau (Lotter *et al.*, 1992). Oscillations described in studies with a less well established ^{14}C chronology could, with respect to standard dating errors, be of the same age as those presented here. Oscillations described in marine records (Lehman and Keigwin, 1992; Koç *et al.*, 1993) have the disadvantage of a problematic ^{14}C chronology as a result of the marine reservoir effect (Walker, 1995); accurate correlation on a chronostratigraphical basis is therefore not possible.

A correlation between the oscillations from Gerzensee (Lotter *et al.*, 1992) presented in figure 3.1 and the vegetation development in The Netherlands can be made. The Aegelsee oscillation (**A**), shortly before 12,000 BP, may be equivalent to sub-zone 1c dated between 12,100 and 11,900 BP.
The oscillation recorded in pollen sub-zone 2a2, dated between 11,500 and 11,250 BP, may be equivalent to the smaller oxygen-isotope oscillation between the Aegelsee and Gerzensee oscillations. Walker and Harkness (1990) dated a fluctuation in *Betula* pollen between 11,400 and 11,300 BP in Llanilid, South Wales. Riezebos and Slotboom (1984) describe a similar palynological oscillation in Kirf, Western Germany. Those fluctuations may be equivalent to the fluctuation in The Netherlands. More accurate dating will be required, however.
The Gerzensee oscillation (**G**) shortly before 11,000 BP and the deposition of the Laacher See tephra (**LST**) is a minor fluctuation that seems not to be reflected in the vegetation development in The Netherlands, though it is possibly obscured by the relatively high pine coverage during this period. However, in eastern North America the Killarney oscillation, dated just before the Late Dryas, can be recognized (Levesque *et al.*, 1993). Levesque *et al.* (1993) correlate this Amphi-Atlantic oscillation with the above mentioned oscillations in Llanilid (Walker and Harkness, 1990) and Kirf (Riezebos and Slotboom, 1984). Regarding the general problems of radiocarbon dating in such small time intervals the Gerzensee oscillation may also be equivalent to sub-zone 2a2 dated between 11,500 and 11,250 BP.
The Younger Dryas oscillation, starting around 11,000 BP, is the most pronounced climatic deterioration recorded by oxygen-isotopes. The oscillation reflected in pollen zone 3, starting at 10,950 BP, is likely to be caused by this climatic deterioration.
Finally, the Preboreal oscillation (**P**) recorded in Gerzensee may be equivalent to sub-zone 4b, dated between 9,950 and 9,750 BP.

3.4 Discussion

Because regional trends in vegetation development can be recognized as synchronous shifts in pollen diagrams from different landscape types, these trends cannot be caused by local influences. Such common trends that can be seen in the vegetation development are considered to be mainly caused by climate. Regional vegetation development can thus serve as a qualitative indicator for palaeoclimate. Palynologically characterized oscillations in The Netherlands are dated to begin at 12,100, 11,500, 10,950 and around 9,950 BP. During these oscillations the vegetation cover was less dense; aeolian influx in organic deposits is also recorded, indicating that the vegetation was indeed more sparse.

It appears that conventional radiocarbon dates can still be very useful in building a regional chronological framework if critically evaluated and considered in a regional perspective. 69 % of the 239 ^{14}C dates fit well in the chronological zonation scheme. Törnqvist *et al.* (1992) showed that bulk samples from pure peats yield similar ages to AMS terrestrial macrofossils. Kilian *et al.* (1996) were able to prove a considerable reservoir effect in peat deposits from Holocene raised bogs, mainly as a result of methane production in much older peat below the sample depth. The reservoir effect in Lateglacial peat deposits is supposed to be of minor importance as the difference in time between the beginning of organic accumulation and the time of formation of the dated Lateglacial peat is relatively small.

At least three plateaux occur within the ^{14}C chronology of the Weichselian Lateglacial, caused mainly by variations in the production of atmospheric ^{14}C. Becker and Kromer (1993) described the most significant plateaux using dendrochronology, the phenomena also being recognized in lake sediments from the Swiss Plateau (Ammann and Lotter, 1989). The position of these plateaux on the radiocarbon time-scale seems to be directly related to fluctuations in climate. Becker and Kromer (1993) located the transition from the Late Dryas stadial to the Preboreal near the end of the 10,000 BP plateau. This implies that this ^{14}C plateau **preceded** the climatic amelioration. The end of the Late Dryas derived from marine and ice-core records, however, indicates a ^{14}C plateau **following** the climatic amelioration as a result of an increased emission of aged CO_2 from the ocean at the beginning of the Holocene temperature rise (Johnsen *et al.*, 1992; Taylor *et al.* 1993; Björck *et al.*, 1996).

The *Artemisia* rise, which indicates the beginning of the Weichselian Lateglacial, is dated at 12,900 BP. The expansions of birch woods as represented by a *Betula* increase in pollen diagrams from The Netherlands are dated at three positions: 11,900, 10,150 and 9,750 BP. The *Artemisia* rise and the expansions of birch are likely to be a result of climatic amelioration. Three such events precede the ^{14}C plateaux at 12,700, 10,000 and 9,600 BP, which supports the idea of a ^{14}C plateau following climatic amelioration. The *Betula* increase at 11,900 BP, however, seems not to be related to any of the known ^{14}C plateaux.

In figure 3.5 a tentative correlation between the GISP2 ice-core (Grootes *et al.*, 1993; Stuiver *et al.*, 1995) and the vegetation development in the Netherlands is presented. Stuiver *et al.* (1995) presented a similar correlation between European pollen zone boundaries and the GISP2 $\delta^{18}O$ climate transitions. Although uncertainties with the calibration of radiocarbon dates from the Lateglacial period occur, the radiocarbon ages of the zone boundaries have been calibrated to calender years (cal yrs BP) according to van der Plicht (1993) and Stuiver and Reimer (1993). The correlation between the regional trends in vegetation development in The Netherlands and the bidecadal $\delta^{18}O$ curve (Stuiver *et al.*, 1995) is rather high. Remarkable is the excellent agreement between the oxygen-isotope shift at 14,670 cal yrs BP and the start of sub-zone 1b, defined by the first rise of *Betula*. This would suggest a zero time-lag between the amelioration of climate and vegetation development. The position of sub-zone 1c, coincides with the small $\delta^{18}O$ dip around 14,000 cal yrs BP. Sub-zone 2a2 might be correlated to the dip around 13,100 cal yrs BP, and is most likely equivalent to the Amphi-Atlantic oscillation (Levesque *et al.*, 1993).

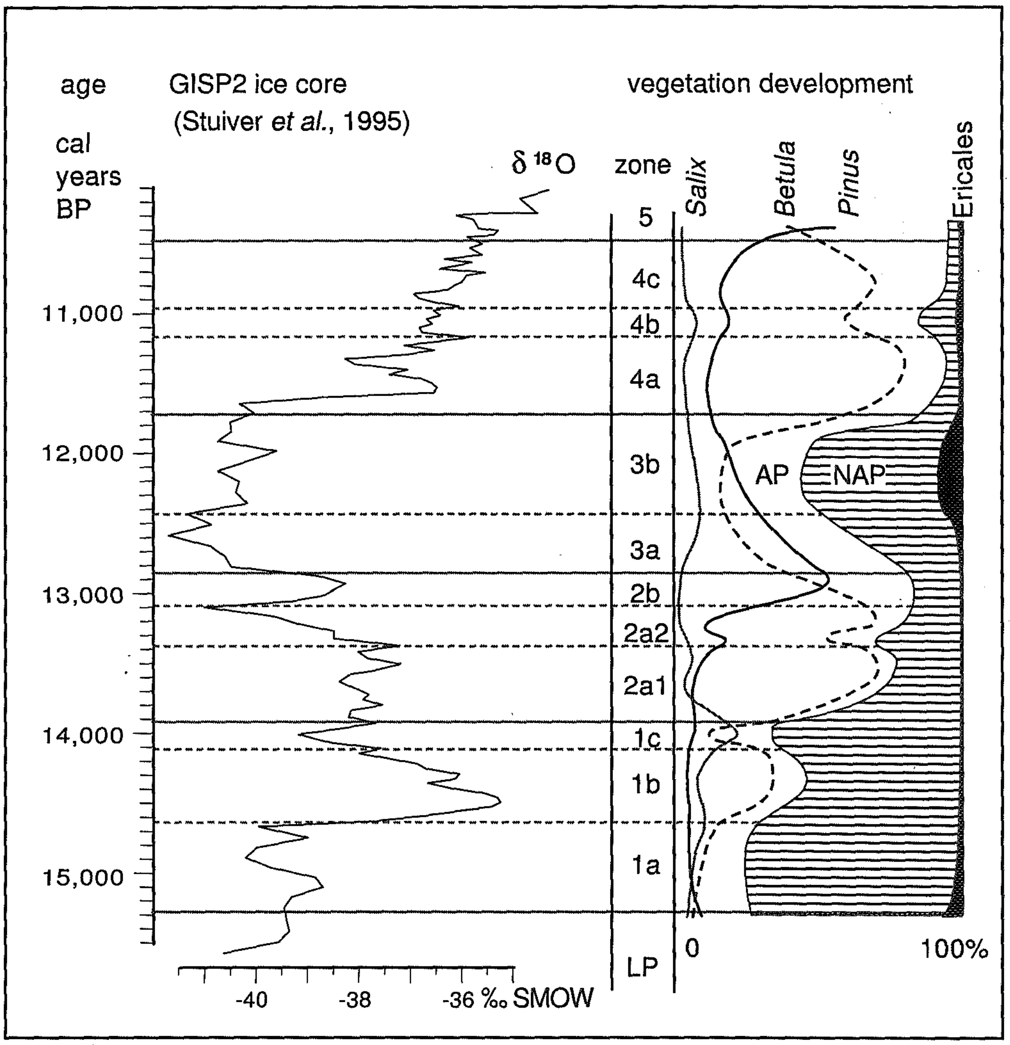

Figure 3.5 Tentative correlation between the GISP2 oxygen isotope curve (Grootes *et al.*, 1993; Stuiver *et al.*, 1995) and the vegetation development in The Netherlands on a calibrated time-scale.

Although a good comparison can be made between the vegetation development and other palaeoclimate signals such as oxygen isotope curves, questions remain about absolute chronology and causal relations between different events in terrestrial, ice-core and marine records (see also Björck *et al.*, 1996). It can, however, be assumed that during the investigated period climate controled plant distribution, because changes in geographical distribution occurred more or less synchronously with changes in climate, as measured by $\delta^{18}O$ (Woodward, 1987).

Appendix 3A-1: AMS- and conventional peat-datings used for constructing the regional zonation scheme (n=134) code: T=top, B=base, U=undifferentiated level

Site name	lab.no.	sample	age	±	code	material	reference
Late Pleniglacial zone LP							
Lattroperstraat 2	Ua-924	216-226	12,885	185	000 U	moss	Ran (1990)
Brugge	Lv-572	24-27	12,870	230	000 T	peat	Vandenberghe *et al.* (1974)
sub-zone 1a							
Usselo I	Ua-382	1975-D	12,930	210	110 B	seeds	van Geel *et al.* (1989)
Usselo I	Ua-381	1975-C	12,840	200	110 B	seeds	van Geel *et al.* (1989)
Usselo I	GrN-1104	BaV	12,540	100	110 T	sandy peat	Lanting and Mook (1977), van Geel *et al.* (1989)
sub-zone 1b							
Gulickshof GH-I	UtC-3196	298	12,480	90	120 B	Betula	Hoek (in prep.)
Stabroek	GrN-2458	132.5	12,460	140	120 B	peaty sand	de Coninck *et al.* (1966)
Usselo I	K-544	BaIV	12,410	140	120 B	peat	Lanting and Mook (1977), van Geel *et al.* (1989)
Mariahout	GrN-13437	040-042	12,400	60	120 U	peat	Bohncke (1993)
Stabroek	GrN-3052	130	12,340	120	120 U	peaty sand	de Coninck *et al.* (1966)
Stabroek	GrN-3049	127.5	12,330	120	120 U	wood	de Coninck *et al.* (1966)
Meeuwerheide-1	GrN-12803	211-213	12,320	70	120 U	peat	van Mourik and Slotboom (1995)
Mariahout	GrN-5914	213-220	12,300	105	120 B	sandy peat	RGD-528a: Zagwijn (1970)
Zelzate	GrN-4782	450	12,300	100	120 U	peat	Paepe and Vanhoorne (1967)
Hulshout 51	GrN-10954	116	12,250	120	120 U	peat	Vandenberghe (1983)
Achterberg	GrN-8844	276-281	12,190	60	120 U	peat	RGD-812a: de Jong (1979)
Bosscherheide I	GrN-13382	033-034	12,110	70	120 B	peat	Bohncke *et al.* (1993)
Achterberg	GrN-17337	256-261	12,110	70	120 U	peat	de Jong (in prep.)
Bosscherheide I	GrN-13381	030-031	12,100	70	120 T	peat	Bohncke *et al.* (1993)
Usselo I	K-542	BaII	12,070	140	120 T	peat	Lanting and Mook (1977), van Geel *et al.* (1989)
sub-zone 1c							
Usselo I	GrN-926	BaI	12,065	120	130 B	peat	Lanting and Mook (1977), van Geel *et al.* (1989)
Achterberg	GrN-17335	232-237	12,050	90	130 U	sandy peat	de Jong (in prep.)
Achterberg	GrN-17338	268-272	12,010	90	130 U	sandy peat	de Jong (in prep.)
Clinge II	GrN-2993	407-410	12,000	110	130 U	peat	RGD-266a: Zagwijn (1961c), Vogel and Zagwijn (1967)
Mariahout	GrN-13438	006-008	11,990	70	130 U	sandy peat	Bohncke (1993)
Moerkerke-Maleveld	GrN-6045	202.5	11,950	65	130 U	peat	Vanhoorne and Verbruggen (1975)
Jabbeke 1	GrN-6654	342.5	11,900	90	130 T	peat	Vanhoorne and Verbruggen (1975)

Appendix 3A-1 *Continued*

Site name	lab.no.	sample	age	±	code	material	reference
sub-zone 2a1							
Notsel	GrN-10833	158-159	11,960	60	211 B	peat	Bohncke *et al.* (1987)
Clinge I	GrN-2891	407-410	11,920	80	211 B	seeds	RGD-266a: Zagwijn (1961c), Vogel and Zagwijn (1967)
Opgrimbie-C	Lv-457	6-11	11,910	170	200 U	peat	Paulissen and Munaut (1969)
Lommel I W. Bergen	Lv-101	206	11,900	330	210 U	peat	Mullenders *et al.* (1958), Deumer *et al.* (1964)
Milheeze Lake	UtC-1976	086-091	11,880	180	211 B	Betula	Bos and Janssen (1996)
Meeuwerheide-1	GrN-12802	179-181	11,860	60	210 U	peat	van Mourik and Slotboom (1995)
Lattropperstraat I	GrN-9683	190-191	11,850	100	210 B	peat	van Hofwegen (1983)
Usselo I	GrN-921	BbII	11,800	100	210 B	peat	Lanting and Mook (1977), van Geel *et al.* (1989)
Amersfoort	GrN-811	169-171	11,780	150	200 B	peat	Zagwijn (1961a), Vogel and Zagwijn (1967)
Oedelem-Geite 3	GrN-6714	359	11,770	65	210 B	peat	Vanhoorne and Verbruggen (1975)
Beerse A	Lv-75N	247.5-252.5	11,750	400	211 U	peat	de Ploey (1963), Deumer *et al.* (1964)
Haskerveenpolder II	GrN-3585	not provided	11,750	100	200 U	peat	Cnossen and Zandstra (1965)
Usselo I	GrN-948	BcIII	11,745	120	210 U	peat	Lanting and Mook (1977), van Geel *et al.* (1989)
Roksem-Hoge Dijken	GrN-5191	260.5	11,740	130	211 U	sandy peat	Vanhoorne and Verbruggen (1969)
Langelede	GrN-8286	180-183	11,730	120	200 U	sandy peat	Kolstrup and Heyse (1980)
Usselo I	GrN-947	BcIII	11,710	90	210 U	peat	Lanting and Mook (1977), van Geel *et al.* (1989)
Usselo I	K-547	BbI	11,700	140	210 U	peat	Lanting and Mook (1977), van Geel *et al.* (1989)
Zandberg	GrN-11469	640-645	11,700	100	200 U	peat	van Dijk *et al.* (1991)
Adegem-Balgerhoeke	GrN-6935	269	11,700	100	210 B	peat	Vanhoorne and Verbruggen (1975)
Milheeze Shore	UtC-1977	078-081	11,700	70	211 U	Betula	Bos and Janssen (1996)
Lommel I W. Bergen	Lv-102	210	11,680	240	210 U	peat	Mullenders *et al.* (1958), Deumer *et al.* (1964)
Denekamp Bejaardenhuis	GrN-4900	252-269	11,630	90	210 U	peat	Wijmstra and Schalke (1971)
Usselo I	K-553	BcIII	11,620	140	210 U	peat	Lanting and Mook (1977), van Geel *et al.* (1989)
Haskerveenpolder A	GrN-2136	224-225	11,600	70	210 U	peat	Cnossen and Zandstra (1965)
Duckenburg XIII	GrN-17031	290-298	11,590	110	211 T	sandy peat	Teunissen (1990)
Kavel A19 SV712-718	GrN-413	477-484	11,560	280	211 U	peat	Wiggers (1955)
Achterberg	GrN-17334	223-229	11,550	80	211 T	sandy peat	de Jong (in prep.)
sub-zone 2a2							
Notsel	GrN-10883	154-155	11,600	50	212 B	sandy peat	Bohncke *et al.* (1987)
Beerse A	Lv-74	240-245	11,550	410	212 U	peat	de Ploey (1963), Deumer *et al.* (1964)
Maarsbergen	GrN-14345	200	11,540	130	212 B	peat	van Mourik and Slotboom (1995)
Achterberg	GrN-17332	190-195	11,540	70	212 U	peat	de Jong (in prep.)

Appendix 3A-1 *Continued*

Site name	lab.no.	sample	age	±	code	material	reference
sub-zone 2a2							
Maartensdobbe	GrN-17139	272-276	11,500	50	210 U	sandy peat	Kasse and Bohncke (1992)
Langelede	GrN-8446	191-194	11,490	110	200 U	sandy peat	Kolstrup and Heyse (1980)
Veenlaag Hamert	GrN-5408	309-312	11,465	50	212 T	peat	Teunissen (1983)
Oedelem vliegend paard	GrN-6715	145	11,395	65	210 U	peaty sand	Vanhoorne and Verbruggen (1975)
Holsbeek-I	Lv-474	280-285	11,330	180	210 U	peat	Mullenders *et al.* (1972)
Adegem-Balgerhoeke	GrN-6936	251	11,330	100	210 T	peat	Vanhoorne and Verbruggen (1975)
Bosscherheide I	GrN-13380	021-022	11,300	60	212 T	peat	Bohncke *et al.* (1993)
Achterberg	GrN-18339	196-199	11,260	60	212 U	peat	de Jong (in prep.)
Meeuwerheide-1	GrN-12431	156-158	11,250	100	210 U	peat	van Mourik and Slotboom (1995)
Denekamp St. Nicolaasst.	GrN-4901	220-232	11,240	65	210 U	peat	Wijmstra and Schalke (1971)
Maarsbergen	GrN-15177	190	11,220	140	212 U	peat	van Mourik and Slotboom (1995)
Achterberg	GrN-17331	178-183	11,160	60	212 U	peat	de Jong (in prep.)
Achterberg	GrN-17330	165-170	11,130	60	212 T	peat	de Jong (in prep.)
sub-zone 2b							
Usselo I	GrN-925	Bcl	11,305	120	220 B	peat	Lanting and Mook (1977), van Geel *et al.* (1989)
Usselo I	K-552	Bcl	11,300	140	220 B	peat	Lanting and Mook (1977), van Geel *et al.* (1989)
Stegerveld III	GrN-3004	low. peat	11,300	90	220 B	peat	Butter (1957), Vogel and Waterbolk (1967)
Ossendrecht	GrN-12743	008-011	11,240	50	220 U	peat	Schwann (1988)
Kavel A19 SV712-718	GrN-410	460-464	11,200	340	220 B	peat	Wiggers (1955)
Achterberg	GrN-17329	153-158	11,200	60	220 B	peat	de Jong (in prep.)
Langelede	GrN-8445	98-101	11,190	120	200 U	sandy peat	Kolstrup and Heyse (1980)
Oeverland nr. 5	GrN-6094	223-230	11,150	95	220 U	peat	de Roever *et al.* (1974)
Maarsbergen	GrN-15176	174	11,120	150	220 B	peat	van Mourik and Slotboom (1995)
Sint Lambrechts Herk	Lv-1239	340-345	11,120	130	220 B	peat	Diriken *et al.* (1991)
Beerse	GrN-12291	185-186	11,100	180	220 U	peat	van Mourik and Slotboom (1995)
Achterberg	GrN-17328	140-145	11,020	60	220 U	peat	de Jong (in prep.)
Milheeze Lake	UtC-1980	065-070	11,010	190	220 B	Betula	Bos and Janssen (1996)
Stegerveld I	GrN-437	top low. peat	11,000	300	220 T	peat	Butter (1957), Vogel and Waterbolk (1967)
Olde Staphorst	GrN-6093	138	10,995	125	220 U	peaty sand	de Roever *et al.* (1974)
Groot Ammers Ia	GrN-6444	1155-1169	10,970	90	220 T	peat	RGD-602a: de Jong and Zagwijn (1977)
Notsel	GrN-9595	128-132	10,970	50	220 T	peat	Bohncke *et al.* (1987)
Achterberg	GrN-17326	119-124	10,960	60	220 T	peat	de Jong (in prep.)

Appendix 3A-1 *Continued*

Site name	lab.no.	sample	age	±	code	material	reference
sub-zone 2b							
Milheeze Shore	UtC-1620	071-072	10,940	110	220 U	Betula	Bos and Janssen (1996)
Bosscherheide I	GrN-13379	009-010	10,940	60	220 T	peat	Bohncke *et al.* (1993)
Achterberg	GrN-17327	125-130	10,940	60	220 U	peat	de Jong (in prep.)
Bosscherheide III	GrN-11569	011-012	10,880	50	220 T	peat	Bohncke *et al.* (1993)
sub-zone 3a							
Snellegem	GrN-6063	99	10,940	60	310 B	sandy peat	Verbruggen (1979)
Westrhauderfehn II	Hv-736-ML	s61-62	10,890	210	310 B	peat	Behre (1966)
Putbroek	GrN-6308	184-190	10,890	65	310 B	peat	Janssen and IJzermans-Lutgerhorst (1973)
Usselo A	Y-139/2	127-132	10,880	160	310 B	sandy peat	van der Hammen (1951), Lanting and Mook (1977)
Maarsbergen	GrN-14344	150	10,870	140	310 U	peat	van Mourik and Slotboom (1995)
Veenlaag Hamert	GrN-4786	303-307	10,870	100	310 B	peat	Teunissen (1983)
Zegers L8	ANTW-134	300	10,860	140	300 U	peat	Heyse (1979)
Beerse	GrN-12290	180-181	10,660	120	310 T	peat	van Mourik and Slotboom (1995)
Pollen diagram I	GrN-10037	297	10,600	50	300 U	peat	de Gans *et al.* (1989)
Lattropperstraat I	GrN-9682	155-156	10,590	60	310 T	peat	van Hofwegen (1983)
Maarsbergen	GrN-15175	130	10,580	90	310 T	peat	van Mourik and Slotboom (1995)
Milheeze Shore	UtC-1618	053-054	10,570	120	310 T	Betula	Bos and Janssen (1996)
Beerse A	Lv-73	230-235	10,560	520	300 U	peat	de Ploey (1963), Deumer *et al.* (1964)
Kavel E155 SV727-729	GrN-375	454-460	10,500	300	310 T	peat	Wiggers (1955)
Bosscherheide III	GrN-11568	002-003	10,500	60	310 T	peat	Bohncke *et al.* (1993)
EEN Schipsloot B	GrN-6341	015-017	10,495	60	310 T	peat	Casparie and ter Wee (1981)
sub-zone 3b							
Duckenburg XIII	GrN-17030	235-240	10,450	260	300 U	sandy peat	Teunissen (1990)
RMO-3	UtC-2727	203	10,440	160	300 U	seeds	van Dinter (1993)
New Dinkel Canal 7	GrN-4723	165	10,300	60	300 U	wood	Wijmstra and de Vin (1971)
Zegers L8	IRPA-159	300	10,250	290	300 U	peat	Heyse (1979)
Pollen diagram I	GrN-10036	263	10,230	150	300 U	peat	de Gans *et al.* (1989)

Appendix 3A-1 *Continued*

Site name	lab.no.	sample	age	±	code	material	reference
sub-zone 4a							
Grauwveen	GrN-12825	173-179	10,150	90	400 U	sandy peat	Teunissen (1986)
De Borchert	GrN-7755	382-383	10,150	90	410 B	peat	van Geel *et al.* (1981)
Vinderhoute-Kale	GrN-6034	252	10,085	90	410 B	peat	Verbruggen (1979)
New Dinkel Canal 5	GrN-4724	130	10,040	60	410 T	peat	Wijmstra and de Vin (1971)
New Dinkel Canal 4	GrN-4731	033	10,030	60	410 T	wood	Wijmstra and de Vin (1971)
Noordzee Boring 68T121	GrN-5758	076-079	9,935	55	410 U	peat	RGD-516a: de Jong and Zagwijn (1973)
De Borchert	GrN-8019	381	9,930	45	410 U	peat	van Geel *et al.* (1981)
sub-zone 4b							
De Borchert	GrN-7756	374	9,850	90	420 B	peat	van Geel *et al.* (1981)
De Borchert	GrN-7757	366	9,800	90	420 T	peat	van Geel *et al.* (1981)
sub-zone 4c							
Zegers L10	IRPA-185	210	9,740	295	400 U	peat	Heyse (1979)
De Borchert	GrN-8021	365	9,730	50	430 B	peat	van Geel *et al.* (1981)
Schuitwater 2A	GrN-17137	208-213	9,705	55	430 T	peat	Kasse *et al.* (1995)
Duckenburg XI	GrN-17027	170-180	9,600	55	430 T	sandy peat	Teunissen (1990)
Wildervank	GrN-1587	095-105	9,570	80	400 T	peaty sand	de Smet and Klungel (1963)
Duckenburg XI	GrN-17028	180-184	9,480	85	430 U	sandy peat	Teunissen (1990)
Noordzee Boring 68T114	GrN-5759	120.5-123.5	9,445	80	400 T	peat	RGD-516a: de Jong and Zagwijn (1973)
De Borchert	GrN-8482	348	9,380	80	430 T	peat	van Geel *et al.* (1981)
zone 5							
Vinderhoute-Kale	GrN-6035	165	9,530	55	500 B	peat	Verbruggen (1979)
Dobbelare L5	ANTW-118	150	9,400	220	500 U	peat	Heyse (1979)
Uitgeest	GrN-1054	2205-2210	9,555	80	500 U	peat	RGD-262: Zagwijn (1961b)

Appendix 3A-2: Conventional clay and gyttja datings which support the zonation scheme (n=30).

Site name	lab.no.	sample	age	±	code	material	reference
Usselo I	GrN-935	BaVI	12,620	130	110 U	gyttja	Lanting and Mook (1977), van Geel *et al.* (1989)
Usselo I	K-546	BaVI	12,530	115	110 U	gyttja	Lanting and Mook (1977), van Geel *et al.* (1989)
Usselo I	K-545	BaV	12,440	140	110 U	gyttja	Lanting and Mook (1977), van Geel *et al.* (1989)
De Mors	GrN-9784	196-202	12,440	130	120 U	gyttja	Castel (unpubl.)
Usselo I	GrN-928	BaVI	12,440	100	110 U	gyttja	Lanting and Mook (1977), van Geel *et al.* (1989)
Mekelermeer MII	GrN-10029	426.5-430.5	12,380	130	120 T	gyttja	Bohncke *et al.* (1988)
Usselo I	K-543	BaIII	12,200	140	120 U	gyttja	Lanting and Mook (1977), van Geel *et al.* (1989)
Moerbeke-Moervaart	GrN-6376	160	12,065	65	130 B	Ca-gyttja	Verbruggen (1979)
Moerbeke-Moervaart	GrN-6032	160	11,955	105	130 B	Ca-gyttja	Verbruggen (1979)
Uddelermeer	GrN-9552	1506-1512	11,980	110	211 B	gyttja	Bohncke *et al.* (1988)
Maarsbergen	GrN-15178	230	11,960	120	210 B	sand	van Mourik and Slotboom (1995)
Spoolde sluisput	GrN-4496	496-500	11,650	170	210 U	gyttja	Hamming *et al.* (1965)
Stegerveld IV	GrN-2411	< lowerpeat	11,600	130	210 U	gyttja	Butter (1957), Vogel and Waterbolk (1967)
De Winge 1981	Lv-1124	240-250	11,550	100	212 B	peaty silt	Munaut (1993)
Beerse	GrN-12298	214-216	11,380	170	200 U	humic sand	van Mourik and Slotboom (1995)
Putbroek	GrN-5842	209-218	11,195	120	212 T	Ca-gyttja	Janssen and IJzermans-Lutgerhorst (1973)
De Mors	GrN-10831	107-117	11,090	60	220 U	gyttja	Castel (unpublished)
Wijchens Ven op de dam	GrN-632	370-390	10,640	240	310 U	clay	Pons (1957)
Wijchens Ven Oostzijde	GrN-16817	427-430	10,590	90	310 T	humic clay	Teunissen (1990)
Wijchens Ven op de dam	GrN-627	332-336	10,580	260	300 U	gyttja	Pons (1957)
Uddelermeer	GrN-9550	1429-1435	10,610	60	320 B	gyttja	Bohncke *et al.* (1988)
Bergen op Zoom	GrN-419	160	10,345	295	300 U	gyttja	van Dorsser (1956)
Wijchen Wezelsche Broek	GrN-10924	444-451	10,320	60	320 U	gyttja	RGD-896a: de Jong (1983)
Bovenbroek 2	GrN-16931	574-576	10,240	120	320 T	gyttja	Teunissen (1990)
Wijchens Ven op de dam	GrN-625	295-300	9,620	205	400 U	gyttja	Pons (1957)
Meerle Bergen-Bruggen	ANTW-272	290-310	9,510	200	500 B	clayey peat	Vandenberghe *et al.* (1984)
Bovenbroek 2	GrN-16930	552-555	9,490	90	400 U	gyttja	Teunissen (1990)
Wijchens Ven op de dam	GrN-660	285-290	9,440	200	430 T	clayey peat	Pons (1957)
Mekelermeer MII	GrN-10026	372.5-374.5	9,410	110	430 T	gyttja	Bohncke *et al.* (1988)
Strabrechts Rond Veen	GrN-9118	170-175	9,260	50	500 U	gyttja	van Leeuwaarden (1982)

Appendix 3B-1: Conventional peat datings that do not fit the zonation scheme (δ +/- less than 500 years, δ ++/-- more than 500 years too old/young) (n=32).

Site name	lab.no.	sample	age	±	zone	δ	material	reference
Opgrimbie-C	Lv-456	54-61	12,640	190	120 U	+	sandy peat	Paulissen and Munaut (1969)
Notsel	GrN-9594	164-169	12,600	60	130 U	++	silty peat ?	Bohncke *et al.* (1987)
Usselo A	Y-139/1	160-165	12,500	180	220 B	++	sandy peat	van der Hammen (1951), Lanting and Mook (1977)
Lattroperstraat 2	Ua-925	226-234	12,315	125	000 U	-	rootlets	Ran (1990)
Veenlaag Hamert	GrN-4787	327-330	12,210	90	130 T	+	peat ?	Teunissen (1983)
Veenlaag Hamert	GrN-5216	321-324	12,160	65	211 B	+	peat ?	Teunissen (1983)
Usselo I	K-541	Bal	11,770	140	130 T	-	sandy peat	Lanting and Mook (1977), van Geel *et al.* (1989)
Achterberg	GrN-17336	244-249	11,770	60	120 U	--	peat/rootlets	de Jong (in prep.)
Polsbroek	GrN-9409	1061-1064	11,470	60	300 U	++	sandy peat	RGD-885: de Jong (1980a)
Usselo A	Y-139/3	107-113	11,350	150	310 T	++	sandy peat	van der Hammen (1951), Lanting and Mook (1977)
Lommel I W. Bergen	Lv-100	197	11,250	240	220 T	+	peat	Mullenders *et al.*(1958), Deumer *et al.* (1964)
Achterberg	GrN-18335	200-204	11,070	60	212 B	-	peat/rootlets	de Jong (in prep.)
Maarsbergen	GrN-15179	150	11,040	70	310 U	+	peat	van Mourik and Slotboom (1995)
Hulshout 51	GrN-9557	84	10,890	60	210 U	--	peat/rootlets	Vandenberghe (1983)
Achterberg	GrN-17790	190-195 (xtr.)	10,870	90	212 U	--	peat	de Jong (in prep.)
Achterberg	GrN-17333	204-209	10,740	60	212 B	--	peat/rootlets	de Jong (in prep.)
Achterberg	GrN-18434	196-204 (xtr.)	10,640	100	212 U	--	sandy peat	de Jong (in prep.)
Achterberg	GrN-17791	204-209 (xtr.)	10,520	90	212 B	--	sandy peat	de Jong (in prep.)
Zegers L10	ANTW-131	210	10,510	160	400 U	++	peat ?	Heyse (1979)
Halle IV-15	GrN-9599	563-567	10,395	100	500 U	++	peat	Bohncke and Vandenberghe (1991)
Duckenburg XI	GrN-10162	200-210	10,360	60	420 U	++	sandy peat	Teunissen (1990)
Keldonk	GrN-9113	364-370	10,350	90	400 T	++	peat	van Leeuwaarden (1982)
Everse Moerkuilen B	GrN-9119	257-260	10,330	80	400 T	++	peat	van Leeuwaarden (1982)
Achterberg	GrN-17325	107-112	10,260	60	220 T	--	peat/rootlets	de Jong (in prep.)
Achterberg	GrN-17789	107-112 (xtr.)	10,240	140	220 T	--	peat	de Jong (in prep.)
Everse Moerkuilen B	GrN-10427	324-325	10,180	100	500 B	++	peat	van Leeuwaarden (1982)
New Dinkel Canal 1	GrN-4722	195	10,010	60	420 U	+	wood	Wijmstra and de Vin (1971)
Petite Nethe I	Lv-459	50-55	9,940	120	500 U	+	peat	Munaut and Paulissen (1973)
Helbroek	GrN-14405	232-236	9,920	190	220 T	--	peat	Teunissen (1990)
Halle IV-15	GrN-10087	529-533	9,640	100	500 U	+	peat	Bohncke and Vandenberghe (1991)
Keldonk	GrN-9112	270-275	9,465	45	500 T	+	peat	van Leeuwaarden (1982)
Annerveen	GrN-1591	115-125	9,380	110	400 U	-	peaty sand	de Smet and Klungel (1963)

Appendix 3B-2: Conventional clay and gyttja datings that do not fit the zonation scheme (δ +/- less than 500, δ ++/-- more than 500 years too old/young) (n=43).

Site name	lab.no.	sample	age	±	code	δ	material	reference
Duckenburg IV	GrN-10161	241-259	12,780	110	130 U	++	clay	Teunissen (1990)
Hamert boorpunt 6	GrN-4478	325	12,760	150	211 B	++	clayey peat	Teunissen (1973)
Lattropperstraat I	GrN-9685	213-214	12,660	300	120 B	+	clay	van Hofwegen (1983)
Vinderhoute-Kale	GrN-6062	496	12,655	70	210 B	++	sandy gyttja	Verbruggen (1979)
Beerendonk VI	GrN-10163	162-172	12,640	310	200 U	++	clay	Teunissen (1990)
Usselo I	GrN-927	BaIII	12,595	170	120 U	+	gyttja	Lanting and Mook (1977), van Geel *et al.* (1989)
Duckenburg XIII	GrN-13217	330-340	12,520	180	210 U	++	humic clay	Teunissen (1990)
Lattropperstraat I	GrN-9684	194-195	12,250	140	130 T	+	humic clay	van Hofwegen (1983)
De Mors	GrN-10832	136-146	12,230	100	210 U	++	Ca-gyttja	Castel (unpubl.)
Usselo I	GrN-933	BcIII	12,115	120	210 U	++	gyttja	Lanting and Mook (1977), van Geel *et al.* (1989)
Mekelermeer MII	GrN-10028	417.5-419.5	12,100	200	210 B	+	gyttja	Bohncke *et al.* (1988)
Oedelem-Geite 2	ANTW-1	358.5	12,060	160	120 U	-	Betula root	Vanhoorne and Verbruggen (1975)
De Winge 1981	Lv-1125	300-310	12,060	120	210 B	+	peaty silt	Munaut (1993)
Oedelem-Geite 2	GrN-6073	358.5	12,010	65	120 U	-	Betula root	Vanhoorne and Verbruggen (1975)
Hamert boorpunt 6	GrN-4508	312	11,900	100	212 B	+	clayey peat	Teunissen (1973)
Halder	GrN-5911	810-820	11,845	105	410 B	++	sandy gyttja	RGD-607: Zagwijn (1971)
Snellegem-Molenbroek	GrN-6061	102	11,780	70	130 U	-	humic peat	Verbruggen (1979)
Alblasserdam LGM	GrN-4087	1768-1788	11,770	120	310 B	++	leaves	RGD-890: de Jong (1980b)
Uddelermeer	GrN-9551	1478-1482	11,720	90	212 T	+	gyttja	Bohncke *et al.* (1988)
Keldonk	GrN-9114	410-415	11,540	100	210 T	+	Ca-gyttja	van Leeuwaarden (1982)
Bosscherheide III	GrN-12165	013-014	11,500	50	220 B	+	soil	Bohncke *et al.* (1993)
Klein Hassels Ven	GrN-9105	340-343	11,450	90	400 T	++	gyttja	van Leeuwaarden (1982)
Maarsbergen	GrN-15229	230 (xtr.)	11,340	130	210 B	--	sand	van Mourik and Slotboom (1995)
Halder	GrN-5910	690-700	11,260	125	430 T	++	gyttja	RGD-607: Zagwijn (1971)
Worsemsche Broek	GrN-13216	230-234	11,220	160	300 U	++	gyttja	Teunissen (1990)
Beerendonk IIIa	GrN-10159	206-214	11,070	200	300 U	+	Ca-clay	Teunissen (1990)
Widooie	Lv-11087	375-380	11,040	30	400 U	++	?	Diriken *et al.* (1991)
Peel (OPE)	GrN-9109	290-294	10,840	60	400 T	++	gyttja	van Leeuwaarden (1982)
Halder	GrN-5909	560-580	10,710	85	500 U	++	gyttja	RGD-607: Zagwijn (1971)
Mekelermeer MII	GrN-10027	412.5-414.5	10,710	230	220 U	-	gyttja	Bohncke *et al.* (1988)
Schelphoek	GrN-2137	1890-1897	10,690	90	400 T	++	gyttja	RGD-230 de Jong (1959), Vogel and Zagwijn (1967)

Appendix 3B-2 *Continued*

Site name	lab.no.	sample	age	±	code	δ	material	reference
Kortessem	Lv-1118	490-495	10,380	100	400 U	+	Ca-gyttja	Diriken *et al.* (1991)
Meerle Bergen-Bruggen	Lv-273	310-330	10,230	320	400 U	+	clayey peat	Vandenberghe *et al.* (1984)
Kortessem	Lv-1119	440-455	10,200	100	400 U	+	Ca-gyttja	Diriken *et al.* (1991)
Schuitwater 2B	GrN-17138	268-276	10,190	50	400 U	+	gyttja	Kasse *et al.* (1995)
Minderhout	GrN-10086	355-360	10,180	90	500 B	++	clayey peat	Bohncke and Vandenberghe (1991)
Halder	GrN-5908	480-490	9,980	110	500 U	++	gyttja	RGD-607: Zagwijn (1971)
Kortessem	Lv-1120	395-415	9,950	85	500 U	+	Ca-gyttja	Diriken *et al.* (1991)
Uddelermeer	GrN-9549	1410-1415	9,940	110	320 T	-	gyttja	Bohncke *et al.* (1988)
Overasseltse Broek LOG	GrN-665	335	9,825	220	500 U	+	clayey peat	Pons (1957)
Everse Moerkuilen A	GrN-10426	240-242	9,720	90	500 T	+	clayey peat	van Leeuwaarden (1982)
Strijbeek	GrN-10752	351-370	9,660	110	500 U	+	gyttja	Beyens (1982)
Keldonk	GrN-9111	224-228	9,430	80	500 U	+	clayey peat	van Leeuwaarden (1982)

Zonation uncertain (n=4)

Site name	lab.no.	sample	age	±	material	reference
Sint Lambrechts Herk	Lv-1145	425-430	12,370	130	clayey peat	Diriken *et al.* (1991)
Sint Lambrechts Herk	Lv-1240	410-415	11,890	150	gyttja	Diriken *et al.* (1991)
Sijsele-Floré L2	ANTW-127	240	11,490	180	wood	Heyse (1979)
Vliermaal-II	Lv-1124	585-590	11,370	150	gyttja	Diriken *et al.* (1991)

4 ABIOTIC LANDSCAPE EVOLUTION AND VEGETATION COVER IN THE NETHERLANDS DURING THE WEICHSELIAN LATEGLACIAL

4.1 Introduction

The Weichselian Lateglacial forms the transition from the cold Pleniglacial to the warmer Holocene. The changes in climate are recorded especially by palynological investigations. However, the changes in climate influenced the whole landscape. Not only the vegetation changed, which is shown by numerous palaeo-ecological studies (Hoek, 1997), but also the abiotic components of the landscape reacted to the climatological changes. Changes in hydrology, transport-mechanisms, erosion, sedimentation and soil development led to changes in the abiotic landscape.
A great number of palynological data considering the Lateglacial have been collected in NW-Europe and especially The Netherlands during the last decades. Therefore, the general vegetation development for this period is well known. From a geological point of view changes in climate occurred very quickly. Mean July-temperature did rise with at least 5°C and similarily changes in precipitation seem to have taken place. These changes in temperature and precipitation were not continuous, during the Lateglacial at least one major break in the temperature rise occurred, e.g. during the Late Dryas-stadial when temperature dropped to such an extent that both vegetation development and the abiotic landscape changed considerably. For the abiotic landscape this climate change caused the formation of riverdunes and coversand-deposits, indicating that the landscape was more open. This abiotical evidence supports the palynological indications for a change from open birch-pine woods towards park tundra with scattered tree bushes. The changes of the vegetation in time can be considered as changes in vegetation patterns, varying within each abiotic landscape type.
In the classical approach, single locations are the main basis for palaeoclimate reconstructions. However, climate parameters derived from single pollen diagrams may be biased by certain local influences. The main reason for this is the fact that not only the large scale changes in climate determine the vegetation development. Also more local variations in lithology, geomorphology and geo-hydrological conditions have influenced the patterns of vegetation development.
The interactions between vegetation and the abiotic landscape are poorly known. Not only changes in the abiotic landscape changes influenced vegetation development and patterns but vegetation on the other hand, affected the abiotic landscape. It can easily be understood that vegetation development affected e.g. sedimentation, erodibility and soil formation.

By a palaeogeographical approach vegetation patterns and changes in these patterns can be compared with geological or geomorphological maps. If the relations between palaeovegetation and the abiotic components of the landscape are known the relations between vegetation and climate can be analysed more clearly. This approach requires a dense network of palynological sections in an area with a well known geology and geomorphology, such as The Netherlands. In the Lateglacial landscape, different geomorphological processes were active.
It will be shown that changes in particularly aeolian and fluvial processes can be related to changes in vegetation. 4.1 shows the locations mentioned in this chapter.

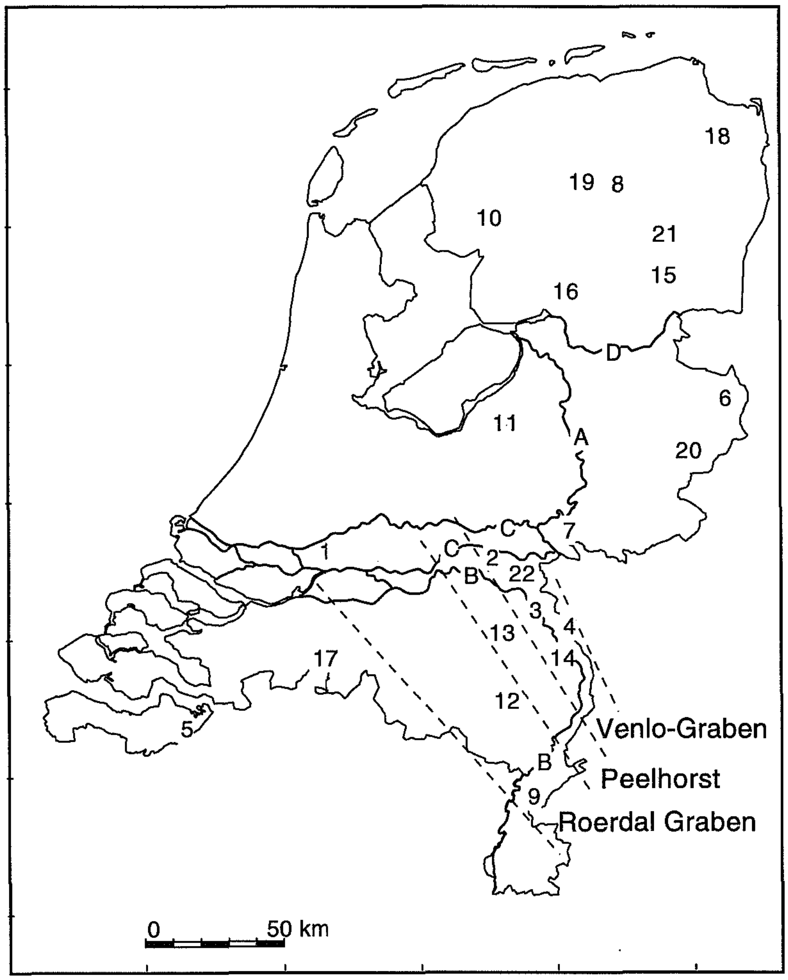

Figure 4.1 Map of The Netherlands with locations mentioned in the text: A:river IJssel, B:river Meuse, C:river Rhine, D:river Vecht, 1:Alblasserwaard, 2:Bergharen, 3:Beugen, 4:Bosscherheide, 5:Clinge, 6:Dinkel valley, 7:Duiven, 8:Een, 9:Gulickshof, 10:Haskerveen polder, 11:Leuvenumse brook, 12:Maartensdobbe, 13:Mariahout, 14:Meerlo, 15:Mekelermeer, 16:Meppel, 17:Notsel, 18:Scheemda, 19:Stokersdobbe, 20:Usselo, 21: Uteringsveen, 22:Wijchens Ven.

4.2 Geomorphological features in the Lateglacial landscape

Periglacial geomorphological processes during the Weichselian Lateglacial were closely related to the distribution of permafrost. The occurrence of continuous, discontinuous or sporadic permafrost is related to Mean Annual Air Temperature (MAAT). Permafrost related phenomena, of which the indicators were frequently preserved in Pleniglacial sediments, must have been scarce during the Lateglacial, as only in some special cases permafrost structures became fossilized in Lateglacial sediments. According to de Groot *et al.* (1987a),

the expression of seasonal climatic variation during the Lateglacial was predominantly influenced by local abiotic factors. These factors determined the formation, evolution and preservation of the frost related phenomena.
Furthermore, changes in lithology during the Lateglacial, which have been recorded in different studies are closely related to changes in geomorphological processes.
The periglacial geomorphological processes that were active at the end of the Pleniglacial disappeared due to the changes in climate in the transition period before the Holocene. Geomorphological changes as a result of climatic change in the Lateglacial were relatively fast.

4.2.1 Permafrost

The occurrence of permafrost related phenomena, in combination with radiocarbon dates of these phenomena, indicate that permafrost was present during the Early Lateglacial and Late Dryas stadial in The Netherlands.

Early Lateglacial
The presence of pingo remnants with a depth varying between 5 meters in the southern Netherlands to 20 meters in the northern Netherlands indicates a minimum thickness of permafrost in the order of those values. As temperature rose only shortly before the Bølling-interstadial (13,000 BP), permafrost most likely started to disappear from that time onward. Melting of the permafrost layer that was several meters thick, probably took hundreds of years. Stapert (1986) concluded on the basis of sedimentological evidence that discontinuous permafrost disappeared in the northern Netherlands during the Allerød interstadial. In chapter 6 will be demonstrated that at Gulickshof, southern Netherlands, the definite disappearance of the Pleniglacial permafrost took place at the beginning of the Allerød (11,900 BP). Other implications for the disappearance of permafrost during the Lateglacial in The Netherlands are given by the start of organic infilling of pingo remnants, dated between 12,450 and 11,900 BP.

Late Dryas
The occurrence of fragipans in the Dinkel valley indicates frost-action phenomena before and after the Allerød (Vink and Sevink, 1971). It is supposed that during the first part of the Late Dryas (10,950 - 10,550 BP), discontinuous permafrost was present again in The Netherlands (Isarin, 1997). Cryoturbations of Late Dryas age, which have been frequently found in The Netherlands, point to mean annual air temperatures of -1°C and indicate at least deep seasonal frost. Thermal contraction phenomena from the Late Dryas have been recorded particularly in the northern Netherlands. These initial ice-wedge casts suggest the occurrence of discontinuous permafrost and a MAAT between -7°C and -2°C (Isarin, 1997). De Groot *et al.* (1987a) described the formation of frost mounds with a radius of about 2.5 meters during the first part of the Late Dryas in Scheemda, northern Netherlands. The presence of such phenomena in the northern Netherlands has been also described by Casparie and ter Wee (1981). Frost mounds are typical for areas with discontinuous or sporadic permafrost and coincides roughly with the -2°C MAAT isotherm (Embleton and King, 1975). The frost mounds in Scheemda are not covered with an isolating layer of coversand from the second part of the Late Dryas. This has led to the conclusion that the preservation of the frost mound structures points to the absence of an active layer and therefore of permafrost, during the latter part of the Late Dryas (de Groot *et al.*, 1987a).

4.2.2 Lithology of Lateglacial deposits

The investigation of numerous Lateglacial deposits shows that a sub-division into different litho-facies can be made. Active geomorphological processes were responsible for the predominant deposition of mineroclastic material.
Deposition of aeolian sands mainly occurred during phases with a low vegetation cover such as Earliest Dryas (12,900 - 12,450 BP), Earlier Dryas (12,100 - 11,900 BP) and Late Dryas (10,950 - 10,150 BP). In basins where organic material could be preserved, a clear distinction can be made between different phases of the Lateglacial.
Formation of lake marls or calcareous gyttja deposits is restricted to warmer parts of the investigated period (see chapter 6). From the beginning of the Bølling period to the end of the Allerød (12,450 - 10,950 BP) and during the Early Holocene (10,150 - 9,150 BP), calcareous gyttjas could be deposited. Periods of peat formation are comparable to that of calcareous gyttja deposits, but in general peat is more commonly preserved than calcareous deposits. Lateglacial peats consist predominantly of sedges or mosses, whereas wood or reed peat is scarce (but see van Geel *et al.*, 1989). The onset of the Late Dryas is often characterized by an abrupt change in lithology. A sudden change from peat or calcareous gyttja to organic gyttja enriched in clastic material has been recorded frequently. In river areas, a change from organic peat or gyttja to clay or silt marks the beginning of the Late Dryas (Bohncke *et al.*, 1993).

4.2.3 Geomorphological processes

The landscape that existed during the Lateglacial in The Netherlands was initially formed by glacial, periglacial, aeolian as well as fluvial processes in the period before the Lateglacial. Some of these processes were still active during the Lateglacial. The presence of a vegetation cover influenced the activity of geomorphological processes. The more dense a vegetation cover, the more resistant is the substratum against erosion. The increasing vegetation cover since the beginning of the Lateglacial is supposed to have diminished the intensity of geomorphological processes. As a result of an increased vegetation cover, soil formation stabilized the substratum. The Usselo-soil is a characteristic soil horizon of Allerød age that is frequently present particularly in the coversand regions. The actual presence of the Usselo-soil indicates that the underlying sediments were protected from erosion during later stages, e.g. the Late Dryas stadial.
The formation of different forms of aeolian phenomena is also closely related to the presence or absence of a vegetation cover and humidity of the substratum. Aeolian erosional phenomena such as desert pavements and deflation hollows together with depositional features such as coversand sheets and dunes were formed simultaneously. The deposition of coversands mainly took place during periods with sparse vegetation cover and bare surfaces. A source area with loose, available sand grains which can be transported by wind is essential for the initiation of aeolian processes on the one hand while on the other hand the presence of a vegetation cover favoures the formation of dunes by interception of sand grains.
Changes in river-pattern are related to changes both in climate and vegetation. As a result of the developing vegetation cover the sediment load of the rivers Rhine and Meuse diminished between the Pleniglacial and Holocene according to Berendsen *et al.* (1995). To a certain extent, brook valleys in the Lateglacial landscape were much alike they are today. Most of the valleys had been formed during the Weichselian Pleniglacial, as a result

of incision into the frozen ground. When permafrost disappeared, the valley forming processes became less intense. Several studies considering the Lateglacial geomorphology of different brook valleys in The Netherlands indicate a similar evolution of these valleys with respect to periods of erosion and sedimentation (e.g. de Gans, 1982; Heijnens and Tijssen, 1982; Vandenberghe *et al.*, 1984, 1987; van Huissteden *et al.*, 1986; de Groot *et al.*, 1987b; Cleveringa *et al.*, 1988).
The diverse landscape types that were present in The Netherlands during the Weichselian Lateglacial reacted in various ways to these changes. Thus the processes, responsible for the formation and changes in geomorphology differ with the landscape type.

4.3 Lateglacial abiotic landscape types

In figure 4.2 a reconstruction of the landscape that existed during the Lateglacial in The Netherlands is presented. In The Netherlands in general five larger landscape types can be distinguished. These landscape types can be defined on the basis of differences in genesis and lithology.

1 ice-pushed landscape
2 till landscape
3 loess landscape
4 coversand landscape
5 river landscape

Within the different landscape types, brook valleys have developed that lead to dissection of the main landscape units. In figure 4.3, the valley distribution based upon the maps by Zagwijn (1986) and van Gijzel and de Gans (1993) is given. This map shows the position of Lateglacial river and brook valleys in The Netherlands.

4.3.1 The ice-pushed landscape

This landscape type was initially shaped under Saalian glacial conditions. During the Saalian glaciation half of The Netherlands had been covered by the Scandinavian ice-sheet. The glaciation caused the elevated topography of the middle and northern Netherlands. The ice-pushed ridges in the central and north-eastern Netherlands were formed by the Saalian ice-sheets. Ice-pushed ridges reaching up to hundred meters in the central part to about twenty meters in the northern part of The Netherlands constitute the main relief-elements of the landscape. Coarse grained sandur deposits are present around the ice-pushed ridges (Ruegg, 1977).
In the ice-pushed region, periglacial slope processes prevailed. The valleys shaped by incision of snow-meltwater in the substratum frozen during the Pleniglacial, were partly filled with aeolian sands and solifluction deposits (van der Hammen, 1951). These processes during respectively drier and wetter parts of the Weichselian Pleniglacial smoothed the initial morphology. Deflation at the windward slopes of the hills caused the formation of desert pavements, whereas the leeward sides were covered with fine grained, aeolian sands. The ice-pushed ridges are built from underlying fluvial sands and gravels and therefore have well-drained soils. As the ice-pushed ridges consist of mainly well-drained sediments, only a few wet basins occur were organic deposits could be preserved.

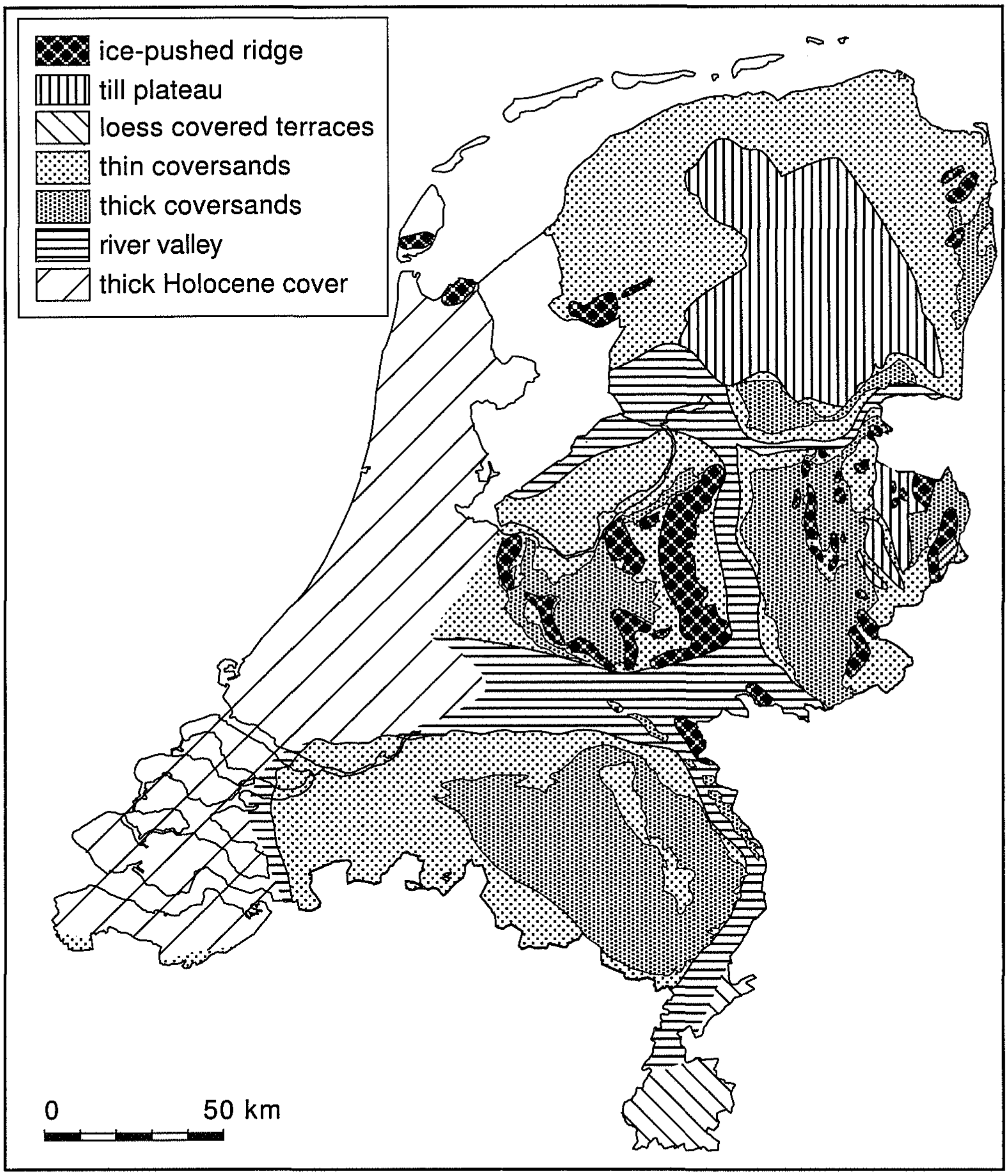

Figure 4.2 Reconstruction of the landscape in The Netherlands during the Weichselian Lateglacial (modified after Maréchal and Maarleveld, 1955; Zagwijn, 1986).

In the ice-pushed landscape, the near absence of datable material makes it often difficult to make a distinction between sediments which originated from processes active during the Pleniglacial and those which were formed by Lateglacial processes. From the evidence available it can be concluded that processes of slope formation and aeolian processes persisted during the Lateglacial. At the base of the ice-pushed hills, springs occurred where

peats could develop in the Lateglacial (Maarleveld and van der Schans, 1961; Verbraeck, 1984). A few pingo remnants occur in the ice-pushed landscape which have been investigated palynologically and geochemically by Bohncke and Wijmstra (1988). In the Leuvenemse beek valley (Polak, 1967; de Gans *et al.*, 1989) Pleniglacial slope deposits and Late Dryas coversand deposits form the substratum in between which Lateglacial organic material could be preserved.
Between the ice-pushed ridges deposition of coversands took place during the Weichselian Pleniglacial and Lateglacial. Low parabolic dunes, palynologically dated as Late Dryas have been described by Maarleveld and van der Schans (1961). These parabolic dunes could be formed because some vegetation cover was present during that time.

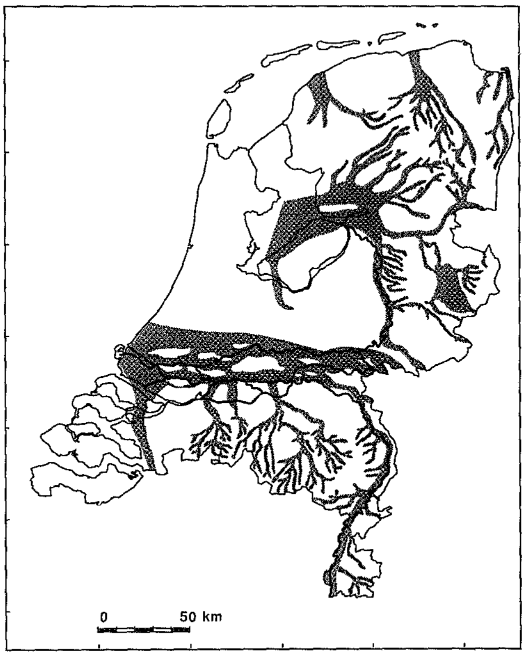

Figure 4.3 The position of Lateglacial river and brook valleys in The Netherlands (modified after Zagwijn, 1986 and van Gijzel and de Gans, 1993).

4.3.2 The till landscape

The till region in the northern Netherlands was also formed as a result of the Saalian glaciation. Large parts of the northern Netherlands were covered with glacial tills. During the Lateglacial these glacial tills formed the substratum carrying locally a thin layer of coversand in a gently undulating landscape. The tills in this area consist of clayey silty matrix with sand, gravel and boulders. The heterogeneity and compaction caused the tills to be badly permeable and this is the main reason for the relatively high groundwater levels in this area. The main geomorphological features in the till landscape are the pingo remnants, that occur frequently in the northern Netherlands. In the till landscape hundreds of Pleniglacial pingo remnants occur (de Gans, 1982).

Pingo remnants have been preserved as circular depressions with or without a distinct rampart and can, for geomorphological reasons, be interpreted as such (Maarleveld and van den Toorn, 1955). Besides this, palynological analyses indicate that the infilling of the depressions started in the Weichselian Lateglacial (Bølling-/Allerød-interstadial), supporting their characterization as remnants of Pleniglacial pingo (Bohncke *et al.*, 1988). The pingo remnants in the northern Netherlands have a radius of up to 150 meters and a maximum depth of 20 meters. The pingo remnants were mainly filled with organic gyttja or peat. Geomorphological processes in the surroundings were recorded in the pingo-remnant infillings. Bohncke and Wijmstra (1988) described indications for unstable soil conditions during the Early and Late Dryas based on chemical analyses from lake deposits in Mekelermeer. In several pingo remnants, aeolian sands were blown into the lakes during the Late Dryas (ter Wee, 1966; Bosch, 1990).
Particularly in the western part of the till region, coversand deposition took place during the Late Dryas (de Groot *et al.*, 1987b). In Haskerveenpolder A & C, Cnossen and Zandstra (1965) described an Allerød peat layer dated by radiocarbon at 11,600 ± 70 BP. This peat was cryoturbated and covered with younger coversand deposits from the second part of the Late Dryas. In the eastern part of the till region aeolian deposition has not been recorded during this period (Bosch, 1990).
In Scheemda A (de Groot *et al.*, 1987a), the start of gyttja deposition in degraded frost mounds was dated in the second half of the Late Dryas, based on palynology. An Allerød peat layer is surrounding the frost mounds, indicating the formation of the frost mounds during the first part of the Late Dryas. In Een-Schipsloot, Casparie and ter Wee (1981) dated the base of the infilling of a frost mound at 10,495 ± 60 BP, which is in full agreement with the palynological date in Scheemda A (de Groot *et al.*, 1987a).
From the center of the Drenthe Plateau, several brook valleys developed forming a radial drainage pattern. The brook valleys dissecting the till landscape have been studied by e.g. de Gans (1982), de Groot *et al.* (1987b).

4.3.3 The loess landscape

In the southernmost part of The Netherlands (southern-Limburg) the Quaternary river terraces are covered with thick layers of loess. In a few other places in the central Netherlands also small areas with loess occur. The deposition of the loess mainly took place during the Weichselian Pleniglacial. The Limburg-loess is the northern part of the European Loessbelt. The transition from coversand in the north to loess in the south is a result of along-track size-sorting by northerly winds (Schwan, 1986).
Although the loess cover in the southern Netherlands was deposited by wind action, the main mechanism that influenced the Lateglacial morphology in the loess landscape was solifluction. Along the smaller rivers and brook valleys steep gradients were present and those were the areas were solifluction could occur during the Lateglacial. The solifluction material (colluvium) partly filled the smaller river and brook valleys in this area. In some river valleys peat formation occurred during the Lateglacial and Early Holocene (Janssen, 1960; Kuyl, 1980; van den Broek, 1981), indicating that slope processes had ceased, at least locally.

4.3.4 The coversand landscape

Most of the Netherlands Lateglacial landscape was covered with a layer of aeolian sands. The Older Coversands had been mainly deposited during the Weichselian (Late) Pleniglacial and formed a flat undulating topography. The Younger Coversands were deposited during the Lateglacial and Early Holocene and formed a subdued dune topography. The coversand region in the eastern Netherlands is characterized by layers of coversand deposited between the Saalian ice-pushed ridges. The coversand region in the southern Netherlands is characterized by a gently undulating topography with a sand thickness varying from some meters to decimeters. In the south-western part, Early Pleistocene clayey deposits occur at shallow depth. The presence of the Peelhorst and the Venlo- and Roerdal-Graben resulted in differences in thickness of the coversands in the south-eastern part.
In the coversand area aeolian processes were mainly responsible for the Lateglacial morphology. Organic deposits in this landscape type consist of peats and shallow lacustrine deposits formed in the depressions between coversand ridges (van der Hammen and Wijmstra, 1971; van Geel *et al.*, 1989).
Pingo remnants in the north-eastern coversand region with a Lateglacial infill have been described by e.g. Bijlsma and de Lange (1983) and van der Woude (1984). Some smaller pingo remnants occur in the southern Netherlands coversand region (Bisschops, 1973; van Leeuwaarden, 1982; Bisschops *et al.*, 1985; Kasse and Bohncke, 1992; Hoek and Joosten, 1995). The open system pingos in the southern Netherlands coversand area have a maximum radius of 35 meters with a depth of 5 meters. They probably originated as a result of hydrostatic pressure under conditions of discontinuous permafrost during the Weichselian Pleniglacial. Some of these depressions are filled with calcareous gyttja, implying that hydrostatic pressure and groundwater exfiltration continued after the decay of the ice-cores (Hoek and Joosten, 1995).
In the north-eastern coversand area the main direction of the brook valleys is towards the Vecht river valley in the north and towards the IJssel river valley in the west. In the southern coversand region the main direction of the brook valleys is towards the Meuse-Rhine river valley in the north, whereas drainage from the Peelhorst area is directed to the Meuse river valley in the east. The brook valleys in the coversand regions formed the subject of several detailed geomorphological studies. In the eastern Netherlands, van der Hammen and Wijmstra (1971) made a detailed investigation of the Dinkel valley. In the southern coversand area different authors have contributed to the geomorphological knowledge of Lateglacial landscape e.g. Heijnens and Tijssen, 1982; Vandenberghe *et al.*, 1984; Vandenberghe *et al.*, 1987, Cleveringa *et al.*, 1988.

4.3.5 The river landscape

The subsoil of The Netherlands consists mainly of river sediments from the rivers Rhine, Meuse and Schelde. During the Quaternary these rivers formed a series of terraces which for the Rhine and Meuse can be recognized in the province of Limburg (van den Berg, 1996). Further to the northwest only the youngest terraces can be recognized near the surface. The river region in the central Netherlands is mainly shaped by the rivers Rhine and Meuse and the terrace levels that can be distinguished are of Pleniglacial and Lateglacial age. In the central and western Netherlands, however, terraces are covered with Holocene deposits, becoming increasingly thicker in westerly direction. Investigation

of the Lateglacial fluvial history is therefore predominantly restricted to the central eastern Netherlands. The river landscape during the Lateglacial has been described by e.g. van den Broek and Maarleveld (1963), Berendsen *et al.* (1995) and Kasse *et al.* (1995).
During the Weichselian Lateglacial discharge and sediment load and thus the river pattern changed as a result of climate change. As the rivers changed their patterns and morphology between braiding and meandering as a result of climate change, the abandoned river channels formed the basins where organic deposits could be preserved. By dating these abandoned river channels, the morphological changes of the river patterns can be considered chronologically and a comparison with the vegetation history can be made.
In the second part of the Late Dryas stadial from 10,550 - 10,150 BP, sand was blown out of the river plains forming river dunes along the river valleys on the older terraces.

4.4 The relationship between vegetation and the abiotic landscape

4.4.1 Vegetational and geomorphological records

The changes in the abiotic landscape cannot be separated from the changes in vegetation. The vegetation development initiated soil formation and stabilized the substratum. On the other hand the abiotic landscape affected the vegetation development, especially the vegetation patterns (see chapter 5). For the investigation of the direct interactions between vegetation and geomorphological processes, vegetational and geomorphological records need to be combined.
From the pingo remnants in the ice-pushed and till landscape, formed after melting of the pingos at the end of the Pleniglacial, many pollen diagrams have been obtained. The vegetation surrounding the lakes is therefore well known. The pingo lakes provide the best records of Lateglacial and Early Holocene environmental history. Information considering lake-level change and aeolian influx as a result of a diminished vegetation cover can in a direct way be compared with the regional vegetation development (Bohncke and Wijmstra, 1988). From the river region and coversand region both vegetational and geomorphological evidence is available for Lateglacial environmental changes. The influence of vegetation on the geomorphological processes can be demonstrated particularly in relation to aeolian and fluvial activity in The Netherlands.
Lateglacial vegetation development in relation to climate and landscape development was investigated by van der Hammen en Wijmstra (1971) in the Dinkel valley (eastern Netherlands). This study provided a comprehensive picture of the lithostratigraphic and vegetational development during Middle and Late Pleniglacial, Lateglacial and Early Holocene.

4.4.2 Vegetation cover

In most investigations, a combined vegetational and geomorphological study has not been undertaken. The comparison of vegetation patterns and the abiotic landscape can give information about their relationships. Important for the geomorphological processes is the density of the vegetation cover. The arboreal pollen percentages (AP) are a measure for the forest density. In general it can be stated that higher values occurred during warmer periods.

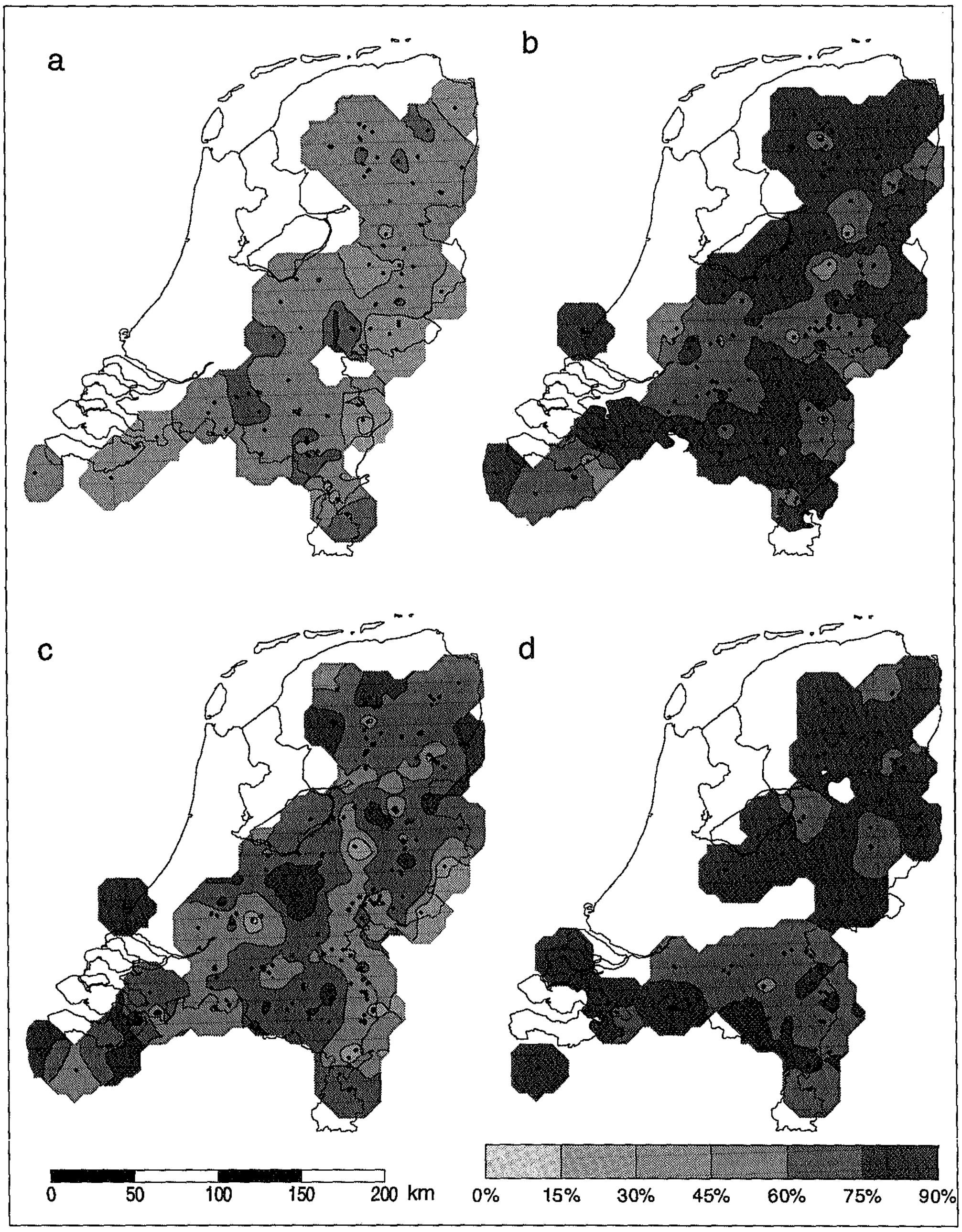

Figure 4.4 Iso-pollen map for AP percentages in The Netherlands (after Hoek, 1997).
a zone 1 or Early Dryas, 12,900 - 11,900 BP.
b zone 2 or Allerød, 11,900 - 10,950 BP.
c zone 3 or Late Dryas, 10,950 - 10,150 BP.
d zone 4 or Early Preboreal, 10,150 - 9,500 BP.

Lower AP percentages are indicative for herbaceous, more open vegetation types of colder intervals. An absolute value for the forest density based on AP percentages is difficult to establish, though relative changes in AP percentage may indicate absolute changes in forest density. Arboreal pollen percentages above 50% approximately indicate the presence of forest (Zagwijn, 1989).
Within the arboreal pollen (AP), the main taxa are *Betula* and *Pinus*, to a lesser extent also *Salix* and *Populus* contribute to the AP percentage. Iso-pollen maps and pollen abundance maps show the changes in vegetation composition and patterns. Iso-pollen maps for AP percentages during different time-windows were constructed based on approximately 250 pollen diagrams. These maps, presented in figure 4.4 (after Hoek, 1997), show the distribution of AP percentages in time and space.
For the construction of the iso-pollen maps, the locations with their average value for the specific taxa within their distinct zone were retrieved from the database. A squared inverse distance interpolation with a search radius of 20 kilometers has been used. The search radius is in accordance with the possible source area of the regional pollen record. In areas where no data were available within the search radius the outcome has automatically been blanked. Thus no extrapolations towards areas without data have been made. The data points used in the interpolation are displayed as black dots.

Figure 4.4a shows an iso-pollen map for the AP percentages during zone 1. From 12,900 to 11,900 BP (zone 1 or Early Dryas *s.l.*) AP percentages varied around 45%, significant distribution patterns cannot be recognized. The AP percentages below 50% suggest that large parts of The Netherlands were covered by herbaceous communities.
Figure 4.4b shows an iso-pollen map for the AP percentages during zone 2. From 11,900 to 10,950 BP (zone 2 or Allerød) AP percentages increased to values above 75%, indicating that forests closed. During sub-zone 2a (11,900 - 11,250 BP) the values vary between 50 and 90%, while for sub-zone 2b (11,250 - 10,950 BP) the values are almost all above 75%. There seems to be a relation between lower AP percentages and the river region, where the vegetation was supposedly more open.
Figure 4.4c shows an iso-pollen map for the AP percentages during zone 3. From 10,950 to 10,150 BP (zone 3 or Late Dryas) the greatest variety in AP percentages occurred with values between 30 and 90%. The forest density in especially the river region was smaller than the preceding zone, which might be related to the larger discharges during this time-interval. The more elevated areas show higher AP percentages.
Figure 4.4d shows an iso-pollen map for the AP percentages during zone 4. From 10,150 to 9,500 BP (zone 4 or Early Preboreal) AP percentages increased again to values generally above 60%. Lower percentages can be recognized in the southern Netherlands coversand region. These lower AP percentages might be a result of the presence of in the previous zone freshly deposited coversands.

4.5 Aeolian activity and vegetation

In The Netherlands, a sub-division of Lateglacial aeolian deposits can be made on the basis of geomorphological and lithostratigraphical indications. In the coversand areas, a distinction between Older and Younger Coversand can be made. Pleniglacial coversand deposits are described as Older Coversands by van der Hammen (1951; 1971). The Lateglacial (Younger) coversands can be sub-divided into Younger Coversand I and Younger Coversand II, where an Usselo soil or peat layer is present (van der Hammen, 1971). Figure 4.5 gives a schematic lithological cross-section of the profiles that are exposed along the Dinkel river in Twente (eastern Netherlands) on which the Lateglacial lithostratigraphy for The Netherlands is based (modified after Wijmstra and Schreve-Brinkman, 1971).

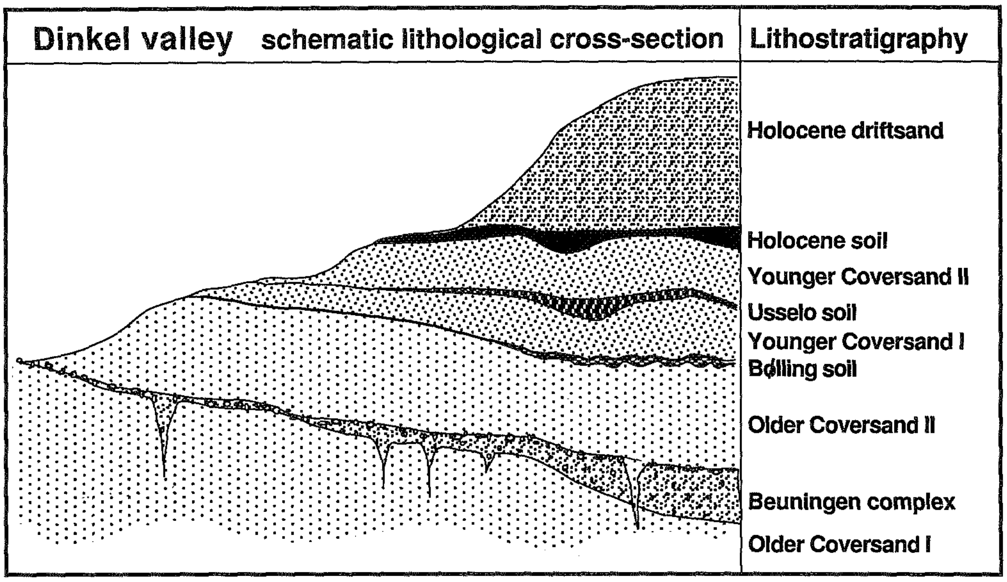

Figure 4.5 Schematic lithological cross-section of the profiles exposed along the Dinkel river in Twente (eastern Netherlands), on which the Lateglacial lithostratigraphy for The Netherlands is based (modified after Wijmstra and Schreve-Brinkman, 1971).

During the Weichselian Pleniglacial, coversand sheets were formed over large areas together with low coversand ridges. Low coversand dunes, mainly of parabolic shape, were formed in areas with a sparse vegetation cover.
During the Weichselian Lateglacial, aeolian processes were still active especially in the coversand areas. The Younger Coversand deposits are usually dune-shaped. The distinct morphology of the Younger Coversand deposits is the result of the presence of a vegetation cover during the time of formation. Particularly during the Allerød (11,900 - 10,950 BP), the vegetation cover was rather dense, and the development of the Usselo-soil (Heijzeler, 1957; van der Hammen, 1951) indicates that aeolian activity was less than during the preceding period.
During the Late Dryas (zone 3, 10,950 - 10,150 BP), coversand was deposited over soils and peats, indicating that the vegetation cover was much more open than during the preceding Allerød. Part of the brook valleys in the southern and eastern Netherlands coversand region were dammed by coversand ridges (van den Toorn, 1967; Bisschops *et al.*, 1985; de Groot *et al.*, 1987b).
In the same period, parabolic river dunes were formed east of the rivers by interception of wind-blown sand into the vegetation that was present at the higher terraces. Several palynological and radiocarbon datings are present to support the dating in the second part of the Late Dryas. Wiggers (1955) gave a date of 10,500 ± 280 BP for the start of river dune formation in the northern Netherlands. Near Meppel (north-eastern Netherlands), de

Roever et al. (1975) dated river dune formation on top of an Allerød peat later than 10,995 ± 125 BP. Van de Meene (1980) described river dunes near Duiven (central Netherlands) overlying a organic deposit, palynologically dated as Allerød or first part of the Late Dryas. Verbraeck (1970, 1974) and Bosch and Kok (1994) describe riverdune formation in the Alblasserwaard, western river area, dating from the same period. Bohncke *et al.* (1993) provided an explicit date of 10,500 ± 60 BP for the start of aeolian deposition in a moss-layer directly underlying river dune deposits in Bosscherheide (southern Netherlands).

Not only geomorphological, but also lithological evidence is present for aeolian activity during the Lateglacial.
From the Earlier Dryas (zone 1c, 12,100 - 11,900 BP), several radiocarbon dates are available for dating the aeolian influx in organic deposits around 12,000 BP; e.g. Clinge II: 12,000 ± 110 (RGD-266A), Usselo I: 12,070 ± 140 BP and 12,065 ± 120 BP (van Geel *et al.*, 1989), Mariahout: 11,990 ± 70 BP (Bohncke, 1993), Bosscherheide I: 12,100 ± 70 BP (Bohncke *et al.*, 1993).
For the aeolian influx within the Allerød *Betula*-phase (zone 2a, 11,900 - 10,250 BP), a radiocarbon date of 11,500 ± 50 BP is given for Maartensdobbe by Kasse and Bohncke (1992). In Notsel a date of 11,600 ± 50 is available for this event (Bohncke *et al.*, 1987).
In many pollen diagrams a change in lithology during the Late Dryas (zone 3, 10,950 - 10,150 BP) from organic to more sandy deposits can be related to an increased aeolian activity in the surrounding landscape. A change in lithology from peat to sand, presumably blown into a depression infilling investigated palynologically at the site Lattroperstraat I is dated at 10,590 ± 60 BP (van Hofwegen, 1983).
Beside a strong aeolian clastic input during the Late Dryas in many sites with organic sediments, aeolian sediments are found also in deposits from Bølling, Allerød and early Holocene age, as shown in e.g. Uteringsveen, northern Netherlands (Cleveringa *et al.*, 1977). This implies that not only during the colder or drier intervals aeolian activity took place, but also in the moister and warmer intervals, indicating that even in such periods the vegetation cover was incomplete. Furthermore, coversand sedimentation into pingo remnants locally continued until the Preboreal, as shown in the site Stokersdobbe, northern Netherlands (Paris *et al.*, 1979).

In chapter 3 it is shown that in The Netherlands the vegetation cover was less dense during periods of change in the palynological record dated to begin at 12,100, 11,500, 10,950 and around 9,950 BP. During these periods an aeolian influx in organic deposits has been recorded frequently, indicating that the vegetation was indeed more sparse. In figure 4.6, a reconstruction of the forest density is given as a curve of the AP (arboreal pollen) and NAP (non arboreal pollen) plotted against an uncalibrated ^{14}C time scale. This curve shows the changes in AP and NAP percentages during the Lateglacial and Early Preboreal and is based on the regional vegetation development for The Netherlands (chapter 3). Figure 4.6 also shows the principal phases of aeolian activity during the investigated period plotted against an uncalibrated ^{14}C time scale.

The rise of the *Empetrum* curve in Lateglacial pollen diagrams in The Netherlands, can generally be dated around 10,550 BP. It coincides in time with the formation of river dunes and coversand ridges during the Late Dryas. *Empetrum nigrum* is a species that is able to grow under active aeolian deposition, and therefore a possible indicator for the presence of aeolian activity during the Late Dryas stadial in The Netherlands. Casparie and Ter Wee (1981) gave a date of 10,495 ± 60 BP for a level at which in the pollen diagram Een-Schipsloot B, the percentage of *Empetrum* is rising just below the coversand filling.

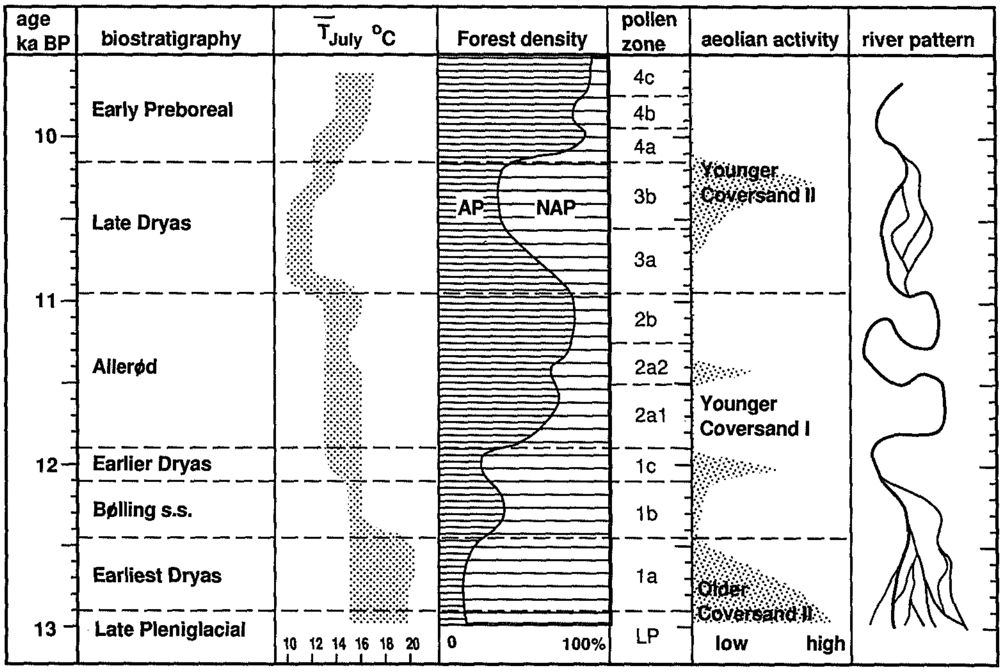

Figure 4.6 Lateglacial climatological, vegetational and geomorphological events plotted against an uncalibrated ^{14}C time scale.

4.6 Fluvial activity and vegetation

In the Maas river valley, a series of abandoned river channels is present which form an archive of fluvial change from the Late Pleniglacial to the Early Holocene (Kasse *et al.*, 1995; van den Berg, 1996; Huisink, 1997).

The river pattern is closely related to both discharge and sediment load, and the role of vegetation with respect to these factors is important. Figure 4.6 shows a schematic overview of the principal fluvial changes in pattern plotted against an uncalibrated ^{14}C time scale.

At the end of the Pleniglacial the rivers Rhine and Meuse (Maas) had a braided pattern in The Netherlands. When permafrost disappeared the peak discharges diminished due to the fact that groundwater could be stored in the soils. The disappearance of the permafrost also diminished the solifluction in the drainage basin, which resulted directly in a decrease of sediment load. Moreover, the increasing vegetation cover stabilized the substratum and thus led to a diminished sediment supply while on the other hand evapotranspiration increased. The rivers reacted to the decrease in discharge and sediment load by changing from a braided towards a meandering pattern during the Lateglacial. The diminished sediment load also supported a tendency to incision in the Bølling-Allerød period. The incision resulted in the abandonment of the Pleniglacial braided river channels. The infilling of these channels started in the Bølling interstadial (Bohncke *et al.*, 1993).

The Lateglacial meandering rivers are characterized by large scale meanders. An neck cut-off oxbow-lake near Beugen with an infilling palynologically dated as early Allerød indicates active meandering during that interval (Kasse *et al.*, 1995).

During the colder Late Dryas stadial the rivers reacted to the deterioration of the climate round 10,950 BP by changing from meandering towards braiding again, while another incision took place. This resulted in the abandonment of the meanders active in Allerød time. The infilling of these abandoned meanders started in the first part of the Late Dryas, palynologically dated near Meerlo (Bohncke *et al.*, 1994). Radiocarbon dates of 10,720 ± 60 BP near Bergharen (Berendsen *et al.*, 1995) and 10,590 ± 90 BP at Wijchens Ven Oostzijde (Teunissen, 1990) indicate that the braided system was active at a lower level from that time onward.
A next, deep incision into the Late Dryas braided river plain occurred at the beginning of the Holocene (Berendsen *et al.*, 1995). The deep incision at the onset of the Holocene was a result of the strong increase of the vegetation cover. As a result of these incisions in the river plain, the groundwater table along the river courses was lowered. Therefore, organic deposits with an Early Holocene age are rare in this region (see figure 4.4d).

4.7 Conclusions

Not only the changes in climate, but also a developing vegetation cover formed an important cause for the changes in geomorphological processes during the Lateglacial. Especially erodibility of the substratum determines the intensity of geomorphological processes. Increasing cohesion by a developing vegetation cover and soil-formation is another factor in Lateglacial geomorphological changes. The arboreal pollen patterns for different zones and sub-zones within the Lateglacial an Early Holocene show a relationship with the abiotic landscape (figure 4.4). Lower tree pollen (AP) percentages can be recognized for the Late Dryas in particularly the coversand and river region. In these areas, large-scale aeolian processes were active and coversand ridges and riverdunes were formed.

The depth of the pingo remnants may be an indication for the minimum thickness of the Pleniglacial permafrost layer (De Gans and Sohl, 1981). This implies that the minimum thickness of the permafrost was between 20 meters in the northern and 5 meters in the southern Netherlands, indicating a possible strong gradient in temperature.

During the Late Pleniglacial the rivers had a braided character as a result of large variations in discharge and sediment load. The vegetation development shows an important increase in the vegetation cover at the beginning of the Allerød-interstadial just after 11,900 BP. Changes in river pattern also took place at that time. This means that both vegetation and fluvial activity were not responding instantaneously to the climatic warming that started just before 13,000 BP. This climatic warming, however, will have played an important role in the melting of the permafrost table. When permafrost completely had disappeared around 12,000 BP, vegetation and rivers reacted almost simultaneously. AP percentages in the river region were generally lower than in other parts of The Netherlands. Presumably, forests could not develop in the river plain during the period under investigation as a result of the dynamic fluvial environment.

5 PATTERNS OF LATEGLACIAL VEGETATION IN THE NETHERLANDS

5.1 Introduction

The Weichselian Lateglacial marks the transition between the cold Weichselian Late Pleniglacial and the warmer Holocene. The climate change during this transition caused the vegetation and the abiotic component of the landscape to change rapidly. A great number of palynological data considering the Lateglacial have been collected in NW-Europe and especially The Netherlands during the last decades. Therefore, the general vegetation development for this period is well known.
At the end of the Weichselian Late Pleniglacial there was in The Netherlands a sparse vegetation cover comprising Gramineae, Cyperaceae and *Betula nana*, many places were altogether bare. From around 13,000 years BP herbaceous plant communities and dwarf bushes developed due to temperature rise. During the Allerød interstadial rather open *Betula* and later on *Pinus* woods occurred. The colder Late Dryas stadial interrupted around 10,950 BP the development to a more dense vegetation cover. The *Pinus* and *Betula* woods diminished in size and herbaceous plant communities comprising *Empetrum nigrum* developed. At the start of the Holocene (10,150 years BP) *Betula* and later on *Pinus* woods expanded again and became more dense as a result of temperature rise. Thermophilous trees as *Corylus*, *Quercus*, *Tilia*, *Ulmus* and *Alnus* appeared later in the Holocene and are supposed to have been absent during the Lateglacial in The Netherlands. This general vegetation development can be recognized in most of the pollen diagrams from The Netherlands. However, pollen diagrams from different areas in The Netherlands show clear variations in pollen composition during the Lateglacial.

5.2 Palaeogeographical approach

For The Netherlands it is to be expected that there were only small spatial differences in climate during the Weichselian Lateglacial due to the small area and relatively large distance to the former coastline. As sealevel was between 90 and 65 meters below the present date level (Jelgersma, 1979), the coastline was more than 200 kilometers away and any climate gradient induced by the sea can be neglected for The Netherlands during the time under investigation. Figure 2.2 shows the relative continental position of The Netherlands during the Weichselian Lateglacial.
In the classical approach, single locations are the main basis for palaeoclimate reconstructions. It is obvious that climate parameters derived from single pollen diagrams will represent certain local influences. The main reason for this is the fact that not only the large scale changes in climate determined the vegetation development in for instance the Weichselian Lateglacial. Also more local variations in lithology, geomorphology and geo-hydrological conditions have influenced the vegetation development and patterns. Palaeoclimate reconstructions based on single pollen diagrams will therefore give a wrong picture of the regional climate.
With a palaeogeographical approach the vegetation patterns and changes in the patterns can be compared with geological/geomorphological maps. As soon as the relations between the palaeovegetation and the abiotic components of the landscape are known, the relations between vegetation and climate will be more clear. This approach requires a dense network of palynological sections in an area with a well known geology and geomorphology.

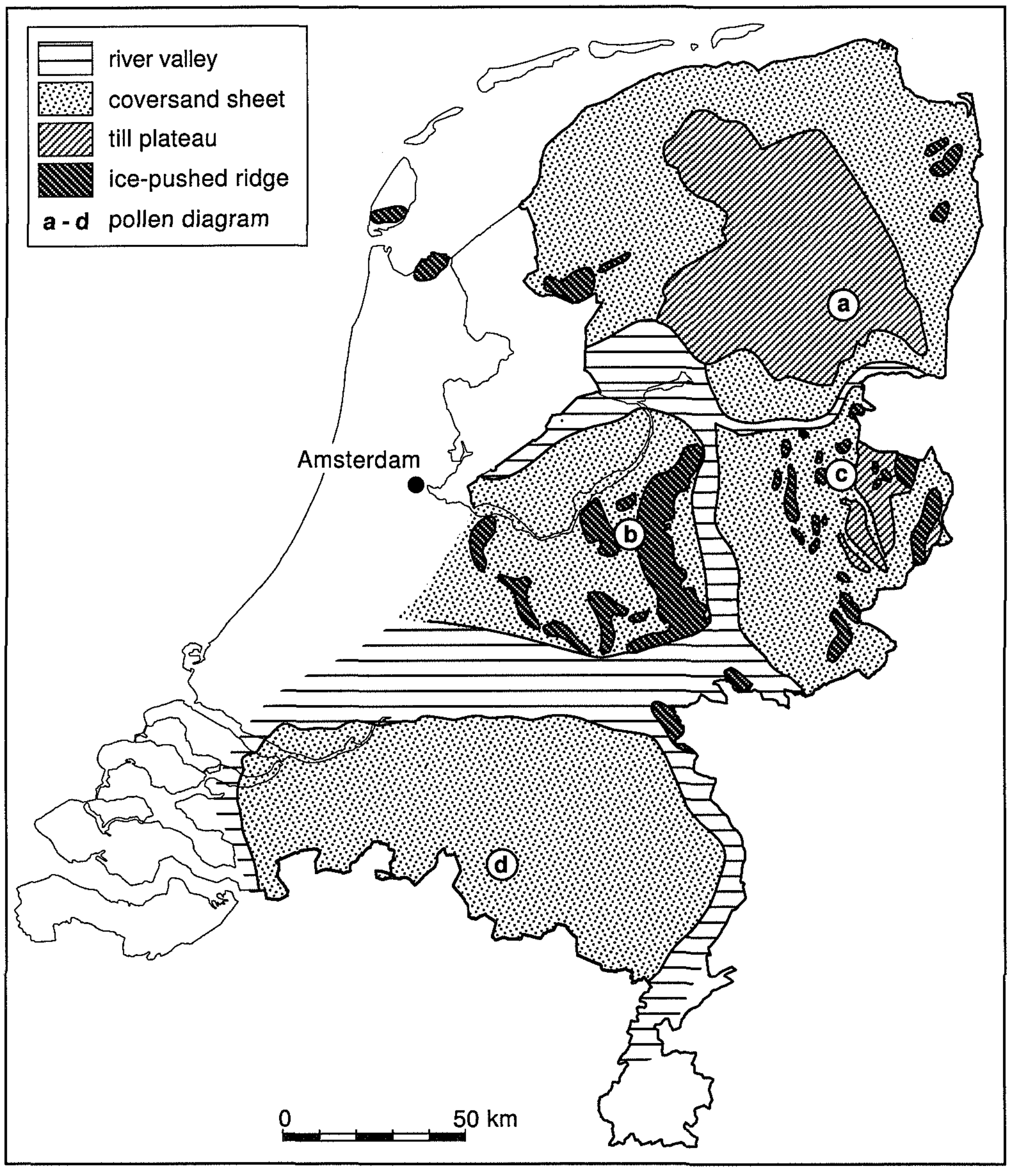

Figure 5.1 Reconstruction of the landscape types in The Netherlands during the Weichselian Lateglacial (modified after Zagwijn, 1986).

5.3 The Lateglacial abiotic landscape of The Netherlands

The Lateglacial landscape is a landscape with changing geomorphology and vegetation. During the Weichselian Lateglacial geomorphological processes were active, but the abiotic changes where not as large as during the preceding Pleniglacial. Morphological features related to permafrost that had existed at the end of the Pleniglacial disappeared due to the changes in climate towards the Holocene. Permafrost disappeared, although deep seasonal frost may have occurred during the Lateglacial (Vandenberghe, 1992). The vegetation development initiated soil formation and stabilized the substratum. The main landscape types that existed during the Lateglacial in The Netherlands are formed by glacial, fluvial and aeolian processes. For The Netherlands in general five larger landscape regions existed during the Lateglacial. In figure 5.1, a reconstruction of the landscape in The Netherlands during the Weichselian Lateglacial is given (modified after Zagwijn, 1986).

5.3.1 Till region

The till region in the northern Netherlands was formed as a result of the Saalian glaciation. Glacial tills form the substratum in a gently undulating landscape. In this region hundreds of Pleniglacial pingo remnants occur (De Gans, 1982). From these pingo remnants, formed after melting of the pingos at the end of the Pleniglacial, many pollen diagrams have been obtained.

5.3.2 Ice-pushed region

The ice-pushed region in the central Netherlands includes the end moraines of the Saalian ice-sheets. The hills rise up to a hundred meters above the surrounding river deposits and are built of older river deposits. Between the ice-pushed ridges deposition of coversands took place during the Weichselian Pleniglacial and Lateglacial (Maarleveld and van der Schans, 1961). As the ice-pushed ridges consist mainly of well-drained gravels and sands, only a few wet basins occur where organic deposits could be preserved.

5.3.3 River region

The river region in the central Netherlands is mainly formed by the rivers Rhine and Meuse. As the rivers changed their patterns and morphology between braiding and meandering due to climate change, the abandoned river channels formed the basins where organic deposits could be preserved. Under dry conditions during the second phase of the Late Dryas stadial, sand was blown out of the braided river beds, forming riverdunes in the surrounding vegetation cover (Bohncke *et al.*, 1993). The river landscape during the Lateglacial has been described by Kasse *et al.* (1995) and Berendsen *et al.* (1995).

5.3.4 Eastern coversand region

The coversand region in the eastern Netherlands is characterized by thick layers of coversand formed during the Weichselian Pleniglacial (Schwan, 1988). In this region also

Saalian ice-pushed ridges occur. During the Late Dryas stadial a layer of coversand was deposited over soils and peats, indicating the landscape was more open than in the preceding Allerød interstadial. The organic deposits in this area consist of peats and shallow lacustrine deposits formed in the depressions between coversand ridges.

5.3.5 Southern coversand region

The coversand region in the southern Netherlands is characterized by a gently undulating topography. The coversands are mainly deposited during the Weichselian Pleniglacial (Schwan, 1988). In the western part, Early Pleistocene clayey deposits occur at shallow depth. Like in the eastern coversand region, organic deposits in this area consist of peats and shallow lacustrine deposits formed in the depressions between coversand ridges. Some smaller pingo remnants occur (Kasse and Bohncke, 1992).

5.4 Preparation of the palynological data

5.4.1 Available palynological data

In The Netherlands over 400 palynological sections have been investigated by several institutes during the last decades, covering part or whole of the Weichselian Lateglacial. Most of the investigated sections are unpublished and the original data are stored as counting sheets in archives of the Geological Survey, Soil Survey and various universities. As a first step in this study, the pollen countings were gathered and inserted into a computer. By now 250 of these sections are available in digital format. The data are stored in a relational database, using the **E**uropean **P**ollen **D**atabase structure. The spatial density of available pollen data decreases in westerly direction, directly related to the depth of the Lateglacial deposits below the present day surface. In the most western part of The Netherlands the Lateglacial deposits are covered with up to 15 meters of Holocene fluvial sediments, marine sediments and peat. Consequently, Lateglacial deposits are difficult to collect. Nevertheless, the spatial resolution is high, as can be seen in figure 2.3. The locations of pollen diagrams which are stored in the database are presented as black dots, while other locations are presented as open circles. With this dense pattern of palynological investigated locations a reconstruction of the vegetation patterns in different time windows during the Weichselian Lateglacial can be made.

5.4.2 Construction of the pollen diagrams

In order to facilitate comparison between the different pollen diagrams, a uniformous pollen sum was used to calculate percentages from the pollen countings. In the pollen sum only non-thermophilous trees, shrubs and dry herbs are included, regional taxa *sensus* Janssen (1973). The local pollen taxa, aquatics and riparian herbs including Cyperaceae, as well as thermophilous tree pollen and spores were excluded from the pollen sum. The major shifts in the main pollen taxa, radiocarbon dated in several pollen diagrams distributed over The Netherlands, are used to construct a regional zonation (chapter 2). In figure 5.2 the zonation is presented as a generalized Lateglacial pollen diagram for The Netherlands on an uncalibrated radiocarbon timescale.

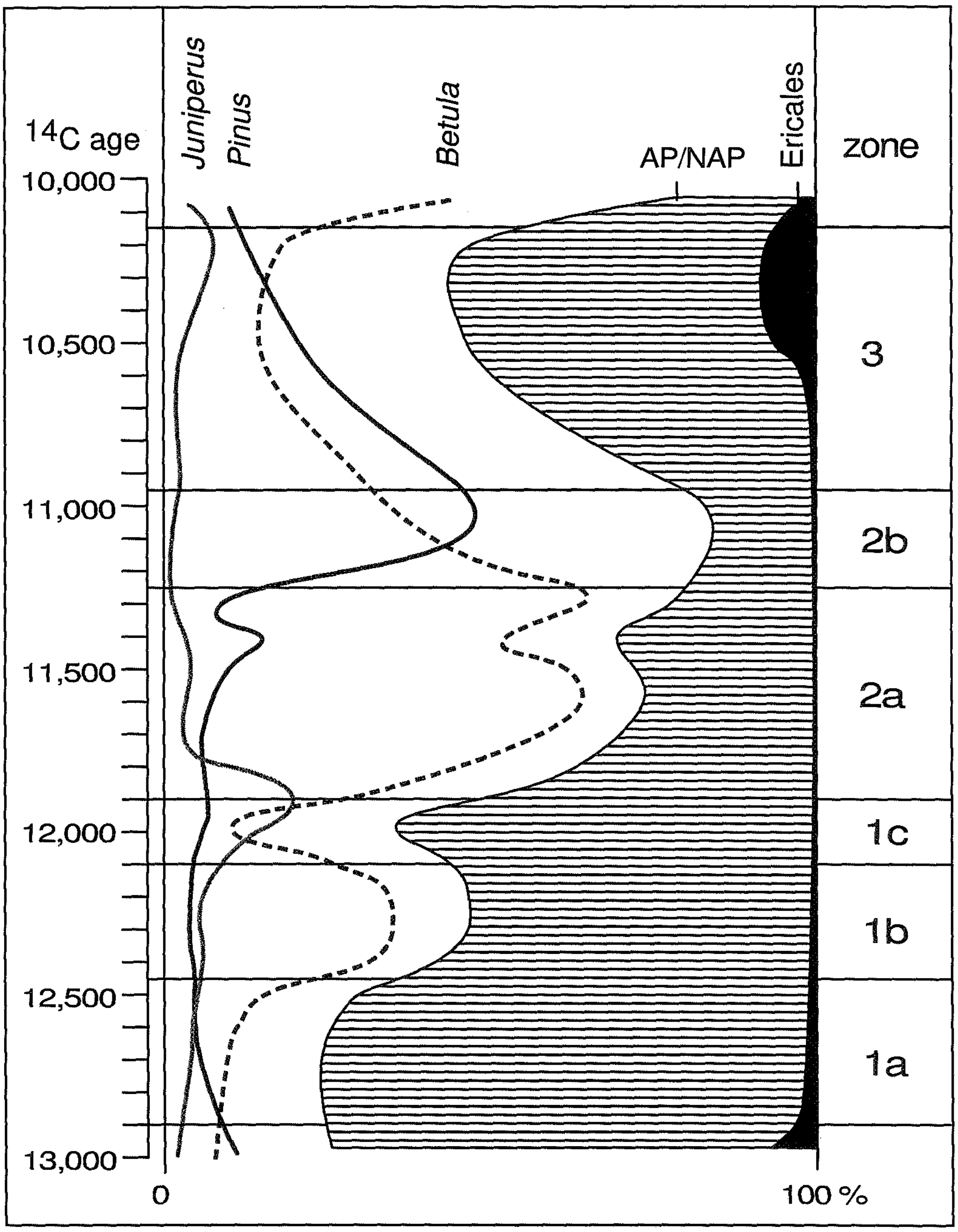

Figure 5.2 Regional Lateglacial pollen diagram with selected taxa for The Netherlands.

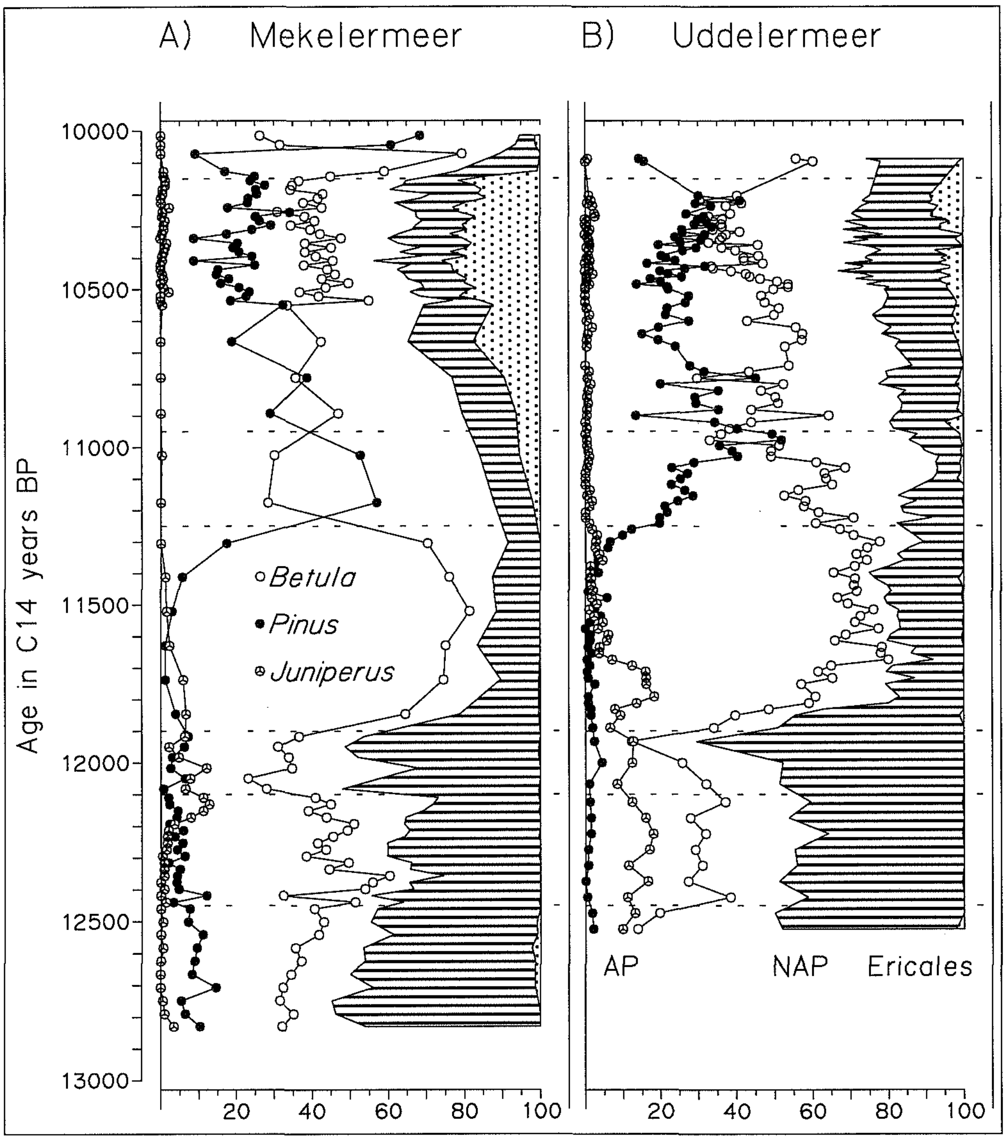

Figure 5.3 Pollen diagrams with selected taxa from 4 small basins in different regions.
a Mekelermeer (Bohncke *et al.*, 1988)
b Uddelermeer (Bohncke *et al.*, 1988)

Based on the zonation, a zone code has been assigned to the analyzed levels from the pollen diagrams in the database. If any uncertainties appeared, for instance in the case of a pollen sum less than 100, indications for reworking or contamination, no zone code was assigned to that level.
In figure 5.3a-d four pollen diagrams with selected taxa are presented. The pollen diagrams are derived from small (former) lakes, pingo remnants from the northern Netherlands till

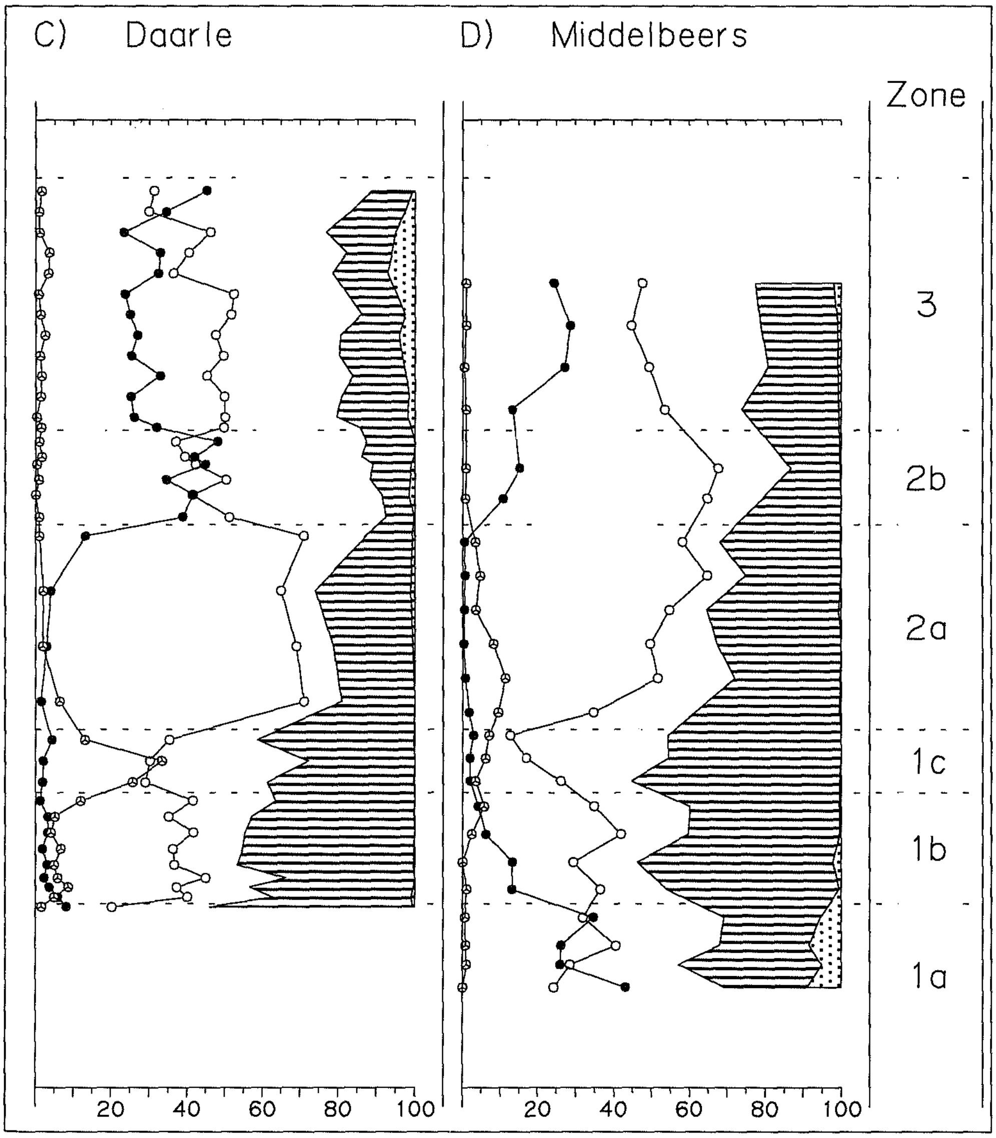

Figure 5.3 Pollen diagrams with selected taxa from 4 small basins in different regions.
c Daarle (Bijlsma and de Lange, 1983)
d Middelbeers (Koelbloed, 1969)

region (a), the central Netherlands ice-pushed region (b) and the eastern (c) and southern (d) coversand region (see figure 5.1 for the locations of the pollen diagrams).
In these diagrams the differences between the percentages of *Juniperus*, *Pinus* and Ericales can be seen. The higher percentages of *Pinus* and Ericales at the, minerogenic, lower part of some of the diagrams are caused by reworking from older deposits.
Juniperus in zone 1c reaches the highest values up to 30% in the diagram from the eastern

coversand region (c) and 15% in that from the central Netherlands (b). During the following zone 2a, the highest values for *Juniperus,* up to 30% are recorded in the diagrams from the central Netherlands and 10% in the southern coversand region (d).
During zone 2b *Pinus* has the highest value round 50% in the diagrams from the till region, the central Netherlands and the eastern coversand region. The values for Pinus in the diagram from the southern coversand region remain below 20%.
The percentages of Ericales, including *Empetrum nigrum*, during zone 3 are the highest in the diagram from the northern Netherlands till region with values up to 25%. The diagrams from the central Netherlands and the eastern coversand region show values up to 10% and 7% respectively.

5.4.3 Construction of the iso-pollen maps

For each pollen diagram in the database the mean and maximum values of the main taxa have been computed for the distinguished zones. For three zones within the Lateglacial, iso-pollen maps were constructed showing the highest percentages of the distinctive taxa in that zone.
Zone 1c and the base of zone 2a are characterized by high values of *Juniperus communis* (Juniper), a species spread by birds and favoured by the presence of a bare sandy substratum.
Zone 2b is characterized by high values of *Pinus sylvestris* (Scots pine) which migrated around 11,250 BP from the south-east, presumably distributed along the river Rhine course.
Zone 3 is characterized by high values of Ericales, especially in the second part of this zone. *Empetrum nigrum* (Crowberrry), the main constituent of the Ericales during this zone is spread by birds. It can be demonstrated that the percentages of the characteristic pollen taxa of each zone vary with the landscape type.

Huntley and Birks (1983) presented iso-pollen maps which show large scale patterns in pollen percentage over Europe. The spatial resolution in these maps of Europe is unavoidably low and these maps cannot be used for regional analyses.
For the construction of the iso-pollen maps in this study, the locations with their maximum value for the specific taxa within their distinct zone were retrieved from the database. Iso-pollen maps were constructed using a squared inverse distance interpolation with a search radius of 20 kilometers. The search radius is in accordance with the possible source area of the regional pollen record. In areas where no data were available within the search radius the outcome has automatically been blanked. Thus no extrapolations towards areas without data have been made. The data points used in the interpolation are displayed as black dots.
For zone 1c and the first part of zone 2a, the time-window from 12,100 - 11,500 BP, the highest percentages of *Juniperus* are plotted in figure 5.4. The presence of *Juniperus* pollen during these zones is recorded in 93 pollen diagrams in the database.
For zone 2b, the time-window from 11,250 - 10,950 BP, the highest percentages of *Pinus* are plotted in figure 5.5. The presence of *Pinus* pollen during pollen zone 2b is recorded in 123 pollen diagrams in the database.
For zone 3, the time-window from 10,950 - 10,150 BP, the highest percentages of Ericales (mainly *Empetrum nigrum*) are plotted in figure 5.6. The presence of Ericales pollen during pollen zone 3 is recorded in 144 pollen diagrams in the database.

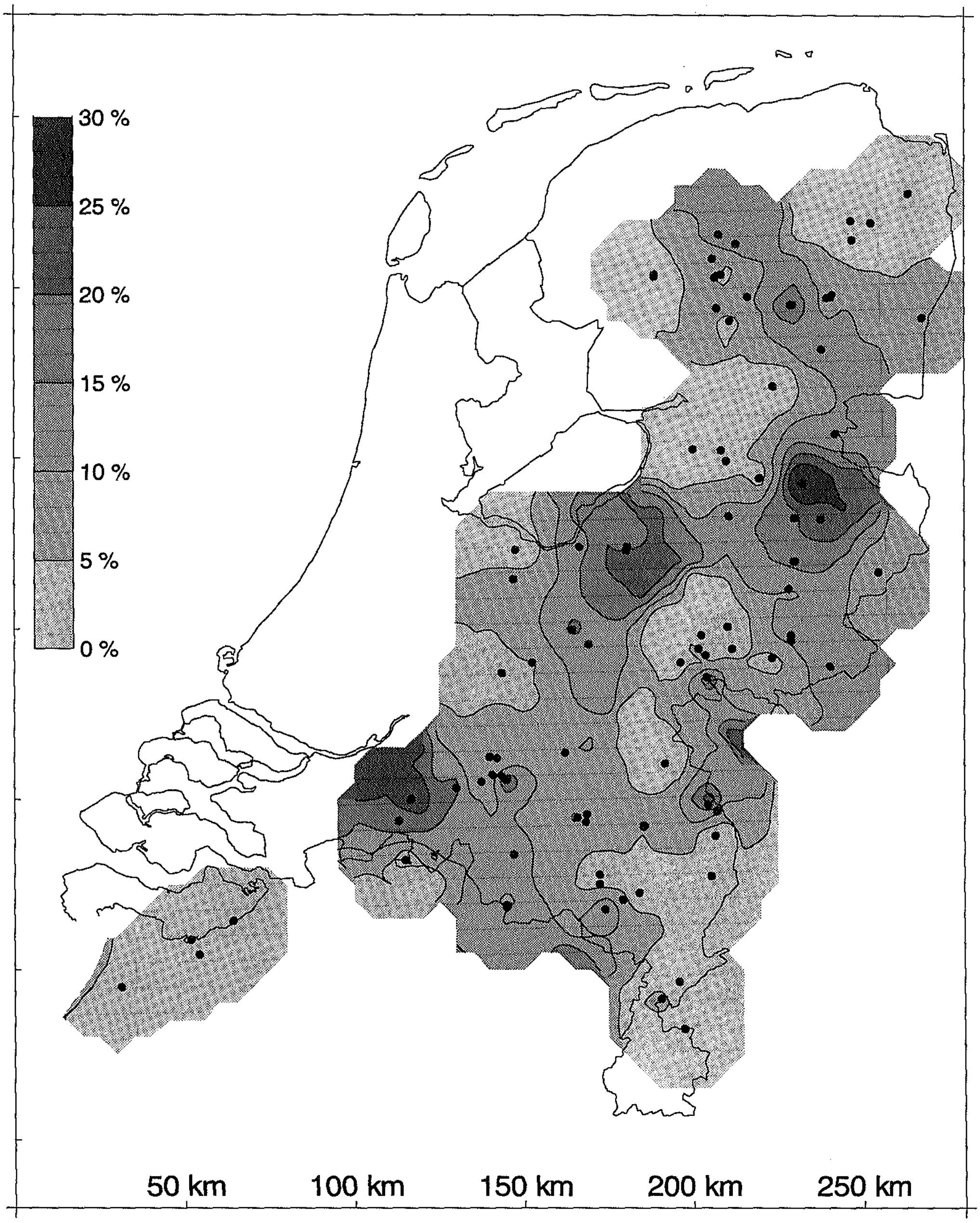

Figure 5.4 Iso-pollen map for the maximum values of *Juniperus* between 12,100-11,500 BP (zone 1c/2a1).

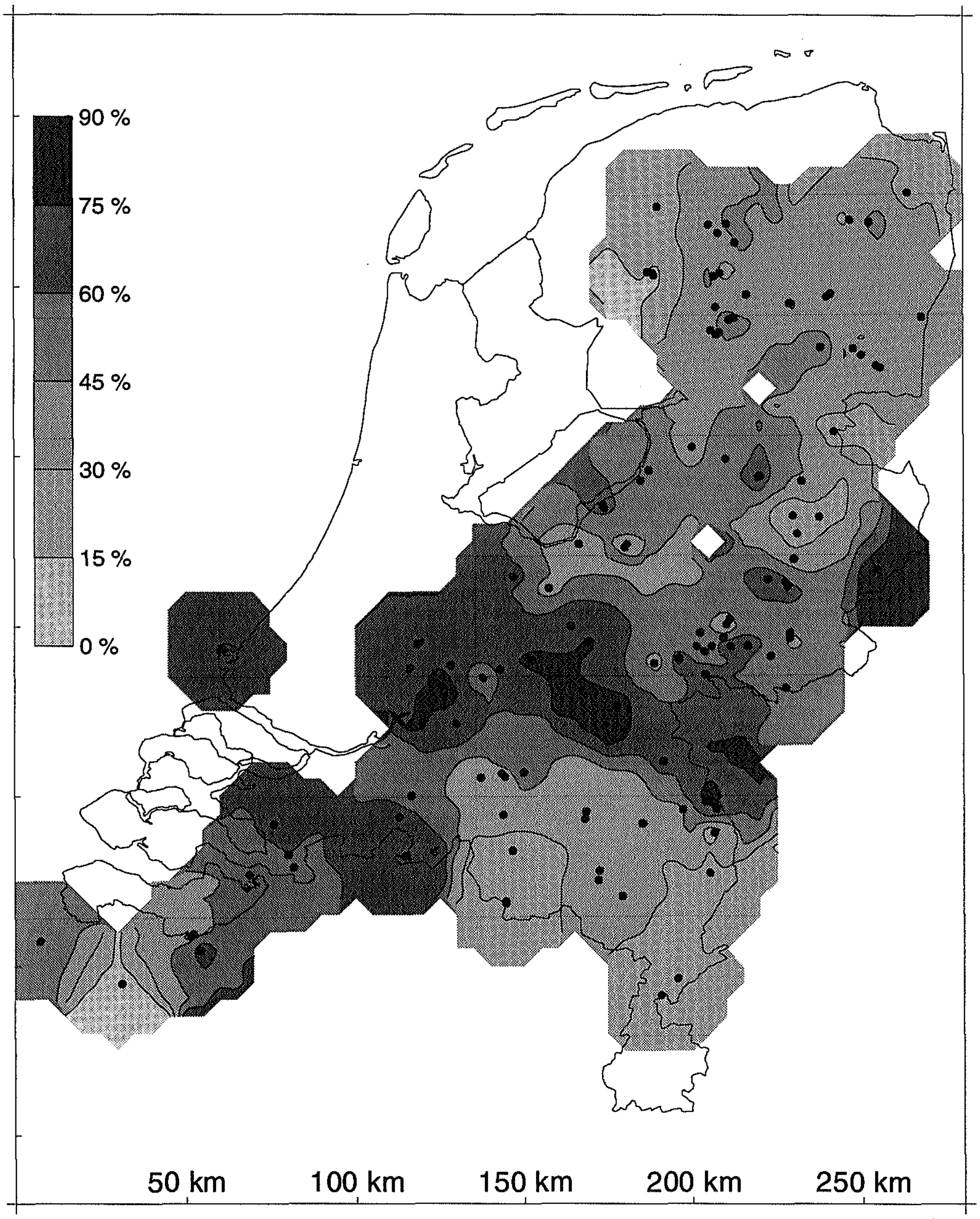

Figure 5.5 Iso-pollen map for the maximum values of *Pinus* between 11,250-10,950 BP (zone 2b).

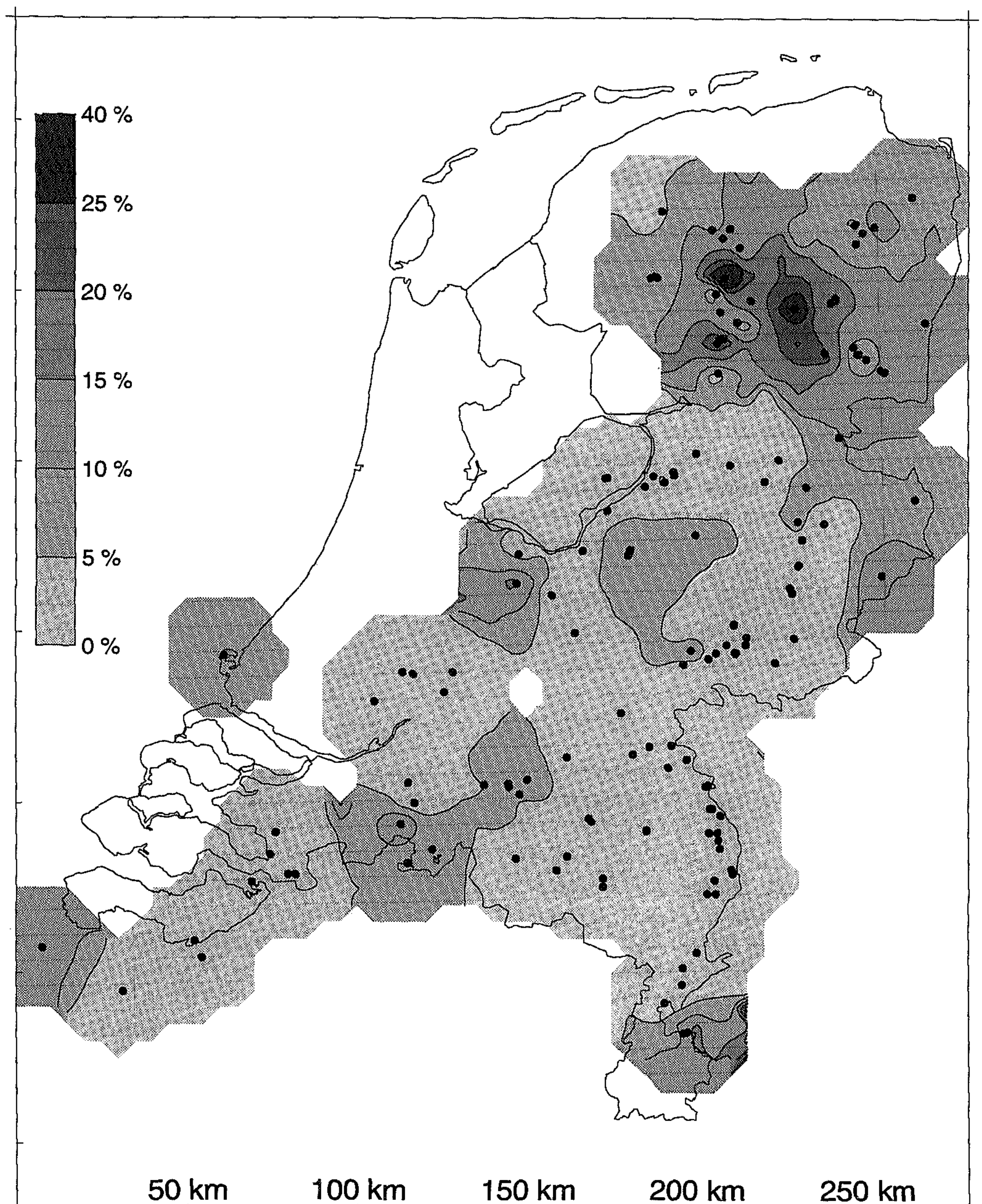

Figure 5.6 Iso-pollen map for the maximum values of Ericales between 10,950-10,150 BP (zone 3).

5.5 Relationship between the iso-pollen patterns and the abiotic landscape

5.5.1 *Juniperus*

The highest percentages *Juniperus* during zone 1c and 2a with values up to 30 percent are related to the ice-pushed ridges in the central and eastern Netherlands and the southern Netherlands coversand region (see figure 5.4). These areas consist of the more sandy well-drained sediments. The growth of *Juniperus communis* is favoured by a bare sandy substratum and is therefore likely to have been growing in the coversand areas. Lower percentages are recorded in the river valleys and the northern Netherlands till region, areas with higher groundwater levels and a less sandy substratum.

5.5.2 *Pinus*

The highest values of *Pinus* during zone 2b are recorded in the central Netherlands river region (see figure 5.5). The lowest values are recorded in the eastern part of the southern Netherlands coversand region. There seems to be no south-north gradient in the percentage of *Pinus* as suggested by some authors. As *Pinus sylvestris* is at present growing on drier locations, it is supposed that *Pinus* was not inhabiting the river valleys but grew on the higher parts of the terraces along the river valleys. High percentages of *Pinus* in the central Netherlands river region may also be a result of a more open herbaceous vegetation type, suggesting *Pinus* is overrepresented due to long distance transport.

5.5.3 Ericales

The iso-pollen map for the maximum values of Ericales during zone 3 (figure 5.6), shows the highest values, over 20%, linked to the poorly drainage and leached soils in tills situated in the northern Netherlands. In the ice-pushed region of the central Netherlands and western part of the southern Netherlands coversand area percentages above 10% occur, presumably related to the occurrence of a clayey substratum at shallow depth. Pollen diagrams from the coversand areas and the nutrient rich river area show values below 5% for *Empetrum* during zone 3. The high occurrence of *Empetrum nigrum* is often used as an indicator for oceanity, based on higher precipitation rates. At present, a higher occurrence of *Empetrum* indicates a low nutrient availability or acid soils, a situation occurring already in the till region during the time under investigation. *Empetrum* is able to grow in areas with an active aeolian sedimentation, a situation that occurred during the second phase of the Younger Dryas (Bohncke *et al.*, 1993).

5.6 Conclusions

Not only climatic changes (temperature and precipitation) influenced the vegetation development. Also more local variations in lithology, geomorphology and geo-hydrological conditions influenced the vegetation and especially the vegetation patterns. As the vegetation in The Netherlands, and other areas, will not have been uniformous during the Lateglacial one has to be careful with deriving the climate signal from single pollen diagrams.

As The Netherlands occupied a relative continental position during the Weichselian Lateglacial, it is not feasible that differences in the pattern of Ericales during the Late Dryas stadial are caused by a climatic gradient over The Netherlands. There will, however have occurred a climatic event causing the great expansion of *Empetrum nigrum* in the areas favourable for this species.

6 LATEGLACIAL ENVIRONMENTAL CHANGES RECORDED IN CALCAREOUS GYTTJA DEPOSITS AT GULICKSHOF, SOUTHERN NETHERLANDS

(together with S.J.P. Bohncke, G.M Ganssen and T. Meijer)

6.1 Introduction

Calcareous lake deposits permit the study of environmental changes with different tools. With a multi-proxy approach, pollen, plant macro-fossils, fresh-water mollusca, stable isotopes and geo-chemical analyses can be performed and the combined evidence can be used to reconstruct regional and local environmental changes. Especially the oxygen isotope composition has proved to document palaeo-climate fluctuations in Swiss lake sediments (e.g. Eicher and Siegenthaler, 1976; Lotter *et al.*, 1992) which can be correlated with those from Greenland ice-cores (e.g. Grootes *et al.*, 1993; Johnsen *et al.*, 1992). Because calcareous deposits could not be dated accurately with conventional ^{14}C methods, absolute chronology was difficult to establish hitherto. With the introduction of the AMS-dating technique on terrestrial material the time-control on this type of deposits can be improved.

In the province of Limburg, southern Netherlands, some sites exist where Lateglacial calcareous deposits have been found. These calcareous deposits consist of authigenic calcareous gyttjas or lake-marls, formed as a result of oversaturation with calcium carbonate of the lake water. In figure 6.1 the locations of the calcareous gyttja deposits are given in relation to the main tectonic faults in the southern Netherlands. Most of the calcareous deposits are situated in the Roer Valley Graben, where hydrostatic pressure is, even at present, responsible for ground water exfiltration.

From the known calcareous gyttja deposits several pollen diagrams were constructed in the last decades; Gulickshof (Florschütz, 1941; van der Hammen, 1951; this study), Putbroek (Janssen and IJzermans-Lutgerhorst, 1973), Jekerdal (RGD-727) and Weerterbos (Hoek and Joosten, 1995; van Joolen, 1996). All these sites show a Lateglacial vegetation development in which *Pinus* is only marginally present during the Allerød. This in contrast to many other Lateglacial sites in The Netherlands (Hoek, 1997).

Based on van der Hammen (1951) the Gulickshof site was chosen as the most suited site for a multi disciplinary study of the Lateglacial in this area. The chronological framework for the formation of the calcareous deposits has been established by biostratigraphic correlation and AMS-dating of small amounts of terrestrial plant remains. The terrestrial pollen composition shows the regional vegetation development while aquatic pollen taxa together with mollusc assemblages document the changes in the local limnic environment. Stable isotope analysis ($\delta^{18}O$ and $\delta^{13}C$) of the calcareous deposits has been applied.

6.2 Site description

6.2.1 Geological setting

The location of the investigated core is two kilometers east of Susteren (Limburg) near the German border at 51°03'37"N, 05°53'50"E (local coordinates: x=190.729 y=341.214 km.) and an altitude of +29.9 m. above ordnance datum (N.A.P.). The extent of the calcareous gyttja deposits was mapped in detail by approximately 100 hand borings and altitude of the surface was obtained by levelling.

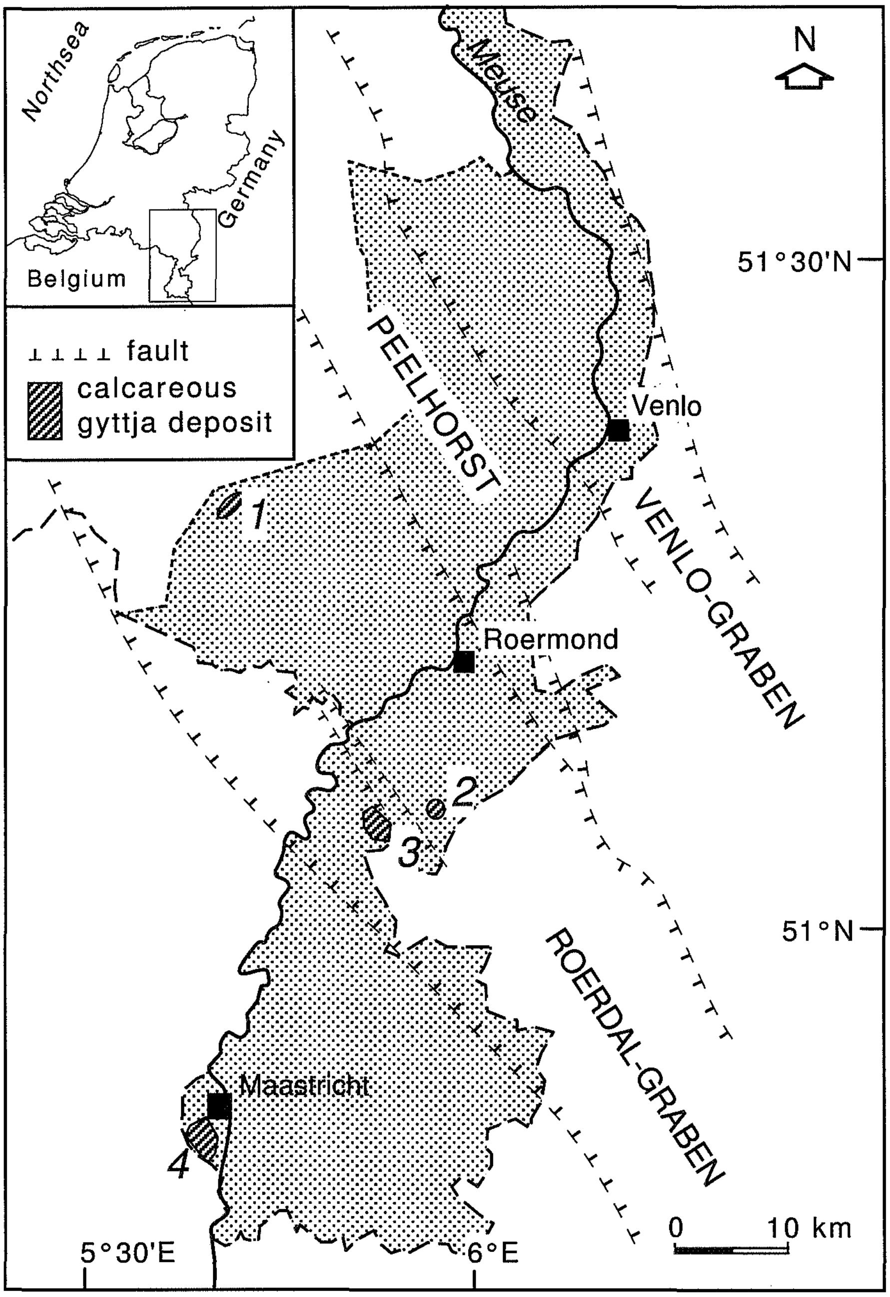

Figure 6.1 Locations with Lateglacial calcareous deposits and main faults in the southern Netherlands (1:Weerterbos, 2: Putbroek, 3:Gulickshof, 4:Jekerdal).

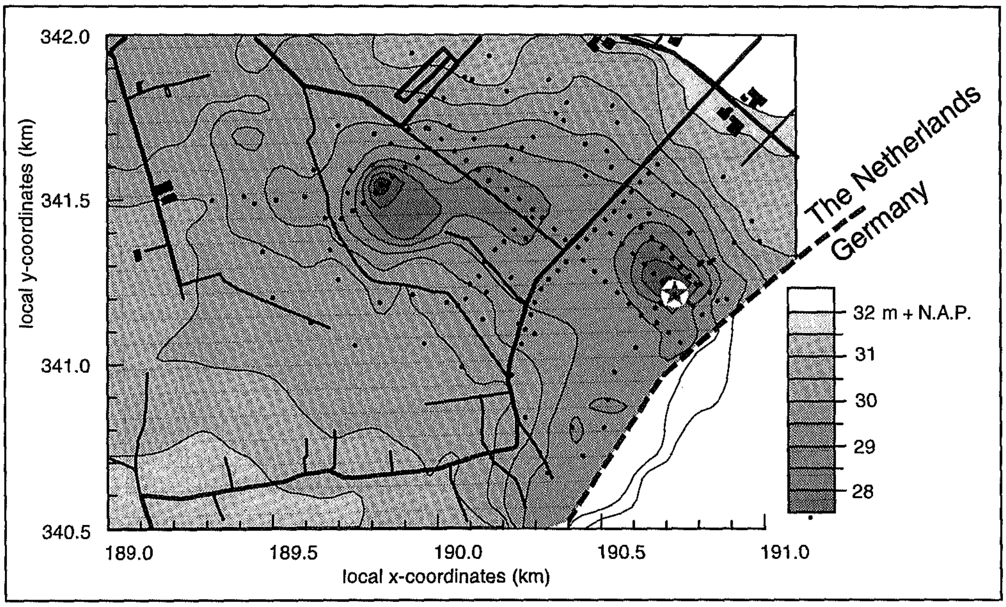

Figure 6.2 Map of the top of the sand deposits in the Gulickshof basin, topography is presented in black, elevation in meters above ordnance level in grey. The location of the core is shown with a star.

The basin in which the calcareous deposits had been formed is a part of the older Weichselian Meuse terrace (Eijsden-Lanklaar) (van den Berg, 1989). The fluvial terrace topography, the top of the gravels and the overlying sandy deposits, show a possible river channel morphology. The divide between the higher area in the northern part and the basin is coinciding with the position of the Koningsbosch fault, which is a part of the Roer Valley Graben (see figure 6.1). In the top of the sand deposits in the basin, two deeper depressions can be recognized (see figure 6.2). The lithological cross section (figure 6.3) shows the infilling of the eastern depression with calcareous gyttja from which the analysed cores were taken.
In view of the geomorphological indications (figure 6.2), the detailed cross section over the depression (figure 6.3) and the Lateglacial age of the basal infill, the depression may be interpreted as remnant of a Pleniglacial ground-ice lens. A similar origin has been suggested for the circular depressions in the Weerterbos area (Hoek and Joosten, 1995) and Putbroek (Janssen and IJzermans-Lutgerhorst, 1973) that are considered to be remnants of open system pingos.

6.2.2 Previous investigations

As early as in 1924, Pannekoek van Rheden has presented a map with the distribution of the calcareous deposits near Gulickshof. The area was included in the geological map from 1938 and the soil map from the early fifties (unpublished draft). These maps could still be used for the distribution of the calcareous deposits, though the original data are lacking.

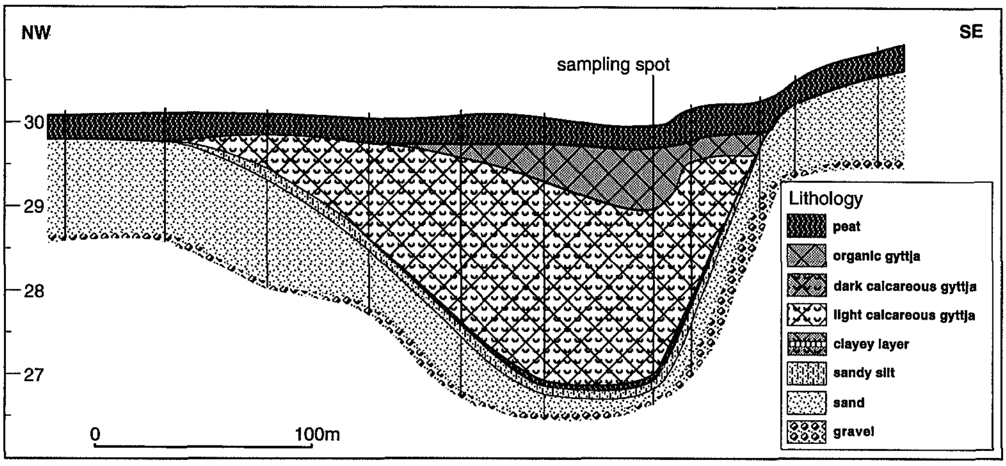

Figure 6.3 Lithological cross-section through the Gulickshof basin.

Part of the calcareous gyttja in the western part of the basin was, however, excavated in the early twenties for the use as fertilizer. The eastern, wettest part has never been excavated or cultivated (Pannekoek van Rheden, 1924), and has still provided an undisturbed section.

The Gulickshof site was previously palynologically investigated by Florschütz (1941) and van der Hammen (1951). Especially in the latter study the pollen diagram shows a rather complete Lateglacial vegetation development from the Late Pleniglacial up to the Late Dryas stadial. The pollen diagram shows a very clear Bølling oscillation, while the transition from the Earlier Dryas towards the Allerød is rather gradual.

6.2.3 Core description

From approximately the same spot as the study by van der Hammen (1951), three cores were taken close to each other (30 cm) with an adapted Livingstone corer (ϕ 6 cm). A gouge auger (ϕ 6 cm) was used for obtaining the topmost 100 cm coarse detrital gyttja and peat.

The available data at the moment of sampling suggested a hiatus at the transition from loamy detritus to peat at 49 cm below the surface (van der Hammen, 1951). The upper 25 cm of the sequence consisting of strongly rooted peat has not been sampled in the field because it was considered to be sub-recent. The location of the core is depicted in figures 6.2 and 6.3. The detailed lithology of the core is presented together with the pollen diagrams (figure 6.4).

Core I and II were used for pollen, macro-remains, ^{14}C-dating, C/N, CaCO3 and stable isotope analysis (δ^{18}O and δ^{13}C). Core III was used for molluscan analysis and ^{14}C-dating.

6.3 Methods

6.3.1 Pollen analysis

From the core, every 5 cm a sample was taken for pollen analysis. Around lithological transitions, the samples were taken every 2.5 cm. The samples were prepared according to the standard method described by Faegri and Iversen (1989). The pollen residues were mounted in glycerine-gelly and glycerine, the latter giving the opportunity to turn the pollen grains for detailed examination.
Identifications were made based on the reference collection of the Faculty of Earth Sciences (Vrije Universiteit Amsterdam), the pollen keys from Moore *et al.* (1991) and the Northwest European Pollen Flora, Volume I-VI by Punt *et al.* (1976, 1980, 1981, 1984, 1988 and 1991).
For percentage computing, an average pollen sum of 400 was used, in the pollen sum only non-thermophilous trees, shrubs and dry herbs are included, regional taxa sensus Janssen (1973). The local pollen taxa, aquatics and riparian herbs including Cyperaceae, as well as thermophilous tree pollen and spores were excluded from the pollen sum. The pollen diagram was constructed using the TILIA and TILIA-graph programs developed by Grimm (1992). The diagram is split into a regional and local part (figure 6.4a and 6.4b).

6.3.2 ^{14}C-dating

The first sample derived from the Gulickshof I core was dated in an early stage to obtain a maximum age of the organic infilling of the basin. *Betula nana* leaves were collected from the moss-layer at the base of the core and dated with AMS at the Van de Graaff Laboratory in Utrecht.
In a later stage, more terrestrial macro fossils were collected by S.J.P. Bohncke from the calcareous gyttja at strategic levels to support the palynological zonation and obtain a chronostratigraphic framework. The latter samples were dated at the Groningen Centre for Isotope Research. Because of the well-known ageing effects of calcareous sediments, AMS-datings on terrestrial macrofossils were prefered. In the samples obtained from the calcareous gyttja between 107.5 and 298 cm, terrestrial macro fossils were scarce. Therefore we decided to include *Menyanthes trifoliata* seeds in our samples. *Menyanthes* being a riparian species, is not supposed to record an ageing effect as it obtains carbon-dioxide from the atmosphere. Because there is not much known about the range of the ageing effects of calcareous gyttjas, along with 2 AMS ^{14}C-datings, samples for conventional ^{14}C-analysis were taken from the same level to get an insight in these effects. The results given in table 6.2 have been corrected for $\delta^{13}C$.

6.3.3 Molluscan analysis

In the lower part of the calcareous gyttja deposits, molluscs are frequently present. In the upper part, between 0 and 170 cm, molluscs were not noticed in the field. From core III at depths between 163 and 294 cm, 27 bulk samples with an average thickness of 5 cm were taken for molluscan analysis. The samples were dried, weighted and organic remains were oxidized with H_2O_2. The samples were sieved over sieves with 4 mm and 250 μm mesh-width, dried and weighted again.

The number of specimens within each sample varied between 0 and 3187. From the fresh-water molluscs, more than 25 taxa could be identified down to species level. Identifications were made by T. Meyer. A small amount of terrestrial taxa was present in the deposits. Fresh-water species are poor indicators for climatic change but can give information about local environmental conditions (Ložek, 1986). At some levels large amounts of *Chara* encrustrations were present in the residues. The estimated weight percentages of calcareous Characeae encrustrations, varies between 0 and 85%. The results are given in figure 6.5.

6.3.4 $CaCO_3$ and C/N analysis

From core I and II every 5 cm a sample was taken for CaCO3, N and C analysis. For the $CaCO_3$-analysis, the calcium carbonate content was measured using the Scheibler-method. Samples with a weight of 1-3 g were dried and crushed. HCl 25% was added to 250 mg of material in a closed cilinder to separate the $CaCO_3$ into CO_3^{2-} and HCO_3^-, the escaping CO_2-gas was measured volumetrically. The results are given as percentages of $CaCO_3$ which vary between 0 and 94%. For the C/N analysis 10-20 mg sample was decalcified, burned and analysed using a Carlo Erbee gas-chromatograph. The results are plotted as a curve against depth in figure 6.8.

6.3.5 Stable isotope analysis

For the analysis of stable oxygen and carbon composition of the carbonate, about 100 μgr of material was reacted with 100% phosphoric acid at 70°C. Measurements were performed by G.M. Ganssen with a Finnigan MAT-251 mass-spectrometer combined with a Finnigan MAT automatic preparation line. All samples were measured *in duplo*, the analytical precision of an internal standard is between 0.05‰ and 0.10‰ (1σ) for the measuring period. The main curves were constructed using untreated samples according to Siegenthaler and Eicher (1986).
Additionally, a series of samples were pretreated by removing the organic fraction and shells. From the selected samples the organic fraction was oxidized chemically with H_2O_2. Because the shell fragments were predominantly coarser than 63 μm, the fraction between 8 and 63 μm was subsequently sieved out for further analysis. The isotope results for $\delta^{18}O$ and $\delta^{13}C$ are presented in figure 6.8 as ‰ deviations from the international PDB-standard (Craig, 1957).

6.4 Regional vegetation development

The regional vegetation development at Gulickshof based on the palynological analysis can be compared with the general Lateglacial regional zonation for The Netherlands presented in table 6.1 (see also chapter 2 and 3). The zone boundaries can be considered as time-lines and are used in the description of the different diagrams for the local vegetation, molluscs, calcium carbonate and stable isotopes. The biostratigraphy presented by van der Hammen (1951) is generally comparable, though less complete, especially in the upper part of the sequence.

Table 6.1 Regional pollen zonation scheme for the Lateglacial in The Netherlands.

age BP	**zone level1**	**sub-level2**	**sub-level3**	**pollen percentage characteristics**
10,150				*Betula* ↑↑, *Juniperus* ↑, NAP ↓
	3	3b	3b	
10,550				*Empetrum* ↑
	3	3a	3a	
10,950				*Pinus* ↓, *Betula* ↓, AP ↓, NAP ↑
	2	2b	2b	
11,250				*Pinus* ↑↑
	2	2a	2a2	
11,500				*Betula* ↓, *Pinus* ↑, *Juniperus* ↓
	2	2a	2a1	
11,900				*Betula* ↑↑, *Salix* ↓, AP ↑↑, NAP ↓↓
	1	1c	1c	
12,100				*Betula* ↓, *Salix* ↑, *Juniperus* ↑, NAP ↑
	1	1b	1b	
12,450				*Betula* ↑, AP ↑
	1	1a	1a	
12,900				*Artemisia* ↑
	Late Pleniglacial (LP)			

6.4.1 PAZ GUL-1 (313-298.5 cm)

The AP (arboreal pollen) percentage is strongly dominated by *Pinus* pollen. The predominantly autochtonous *Betula* and *Salix* percentages are below 10%, suggesting a rather open, herbaceous vegetation cover with tussocks intermingled with a barren substratum. Pollen of *Salix herbacea*, *Salix polaris*-type and *Betula nana* points to birch and willow shrub communities. Representatives of Chenopodiaceae, Papilionaceae, Saxifragaceae are important herbs in this zone. This pollen assemblage points to a moss/shrub tundra with scattered occurrences of *Betula nana* and *Salix* shrubs. Considering the open character of this vegetation type a large amount of the *Pinus* pollen is probably attributable to long-distance transport. Pollen from thermophilous taxa like *Abies*, *Carpinus* and *Ulmus* is present in low values. These thermophilous taxa as well as part of the *Pinus* pollen are interpreted as being reworked pollen from older deposits, a common feature in mineroclastic bottom fills of Lateglacial basins. PAZ GUL-1 compares with regional zone LP or sub-zone 1a (older than 12,450 BP).

6.4.2 PAZ GUL-2 (298.5-277.5 cm)

This zone starts with a rise in *Betula* pollen percentages up to 40%, predominantly tree-birch. Pollen of *Populus* and *Juniperus* is present in low values. The percentage of *Artemisia* pollen gradually increases to a value of 5%. The percentage of reworked pollen diminishes. This assemblage reflects a progressive vegetation development towards an open boreal birch woodland with dispersed birch copses. The displacement of the vegetation belts comprising *Juniperus* was triggered by favourable climatic conditions. AMS-dating on *in situ Betula nana* leaves from the base of this zone (298 cm) yielded an

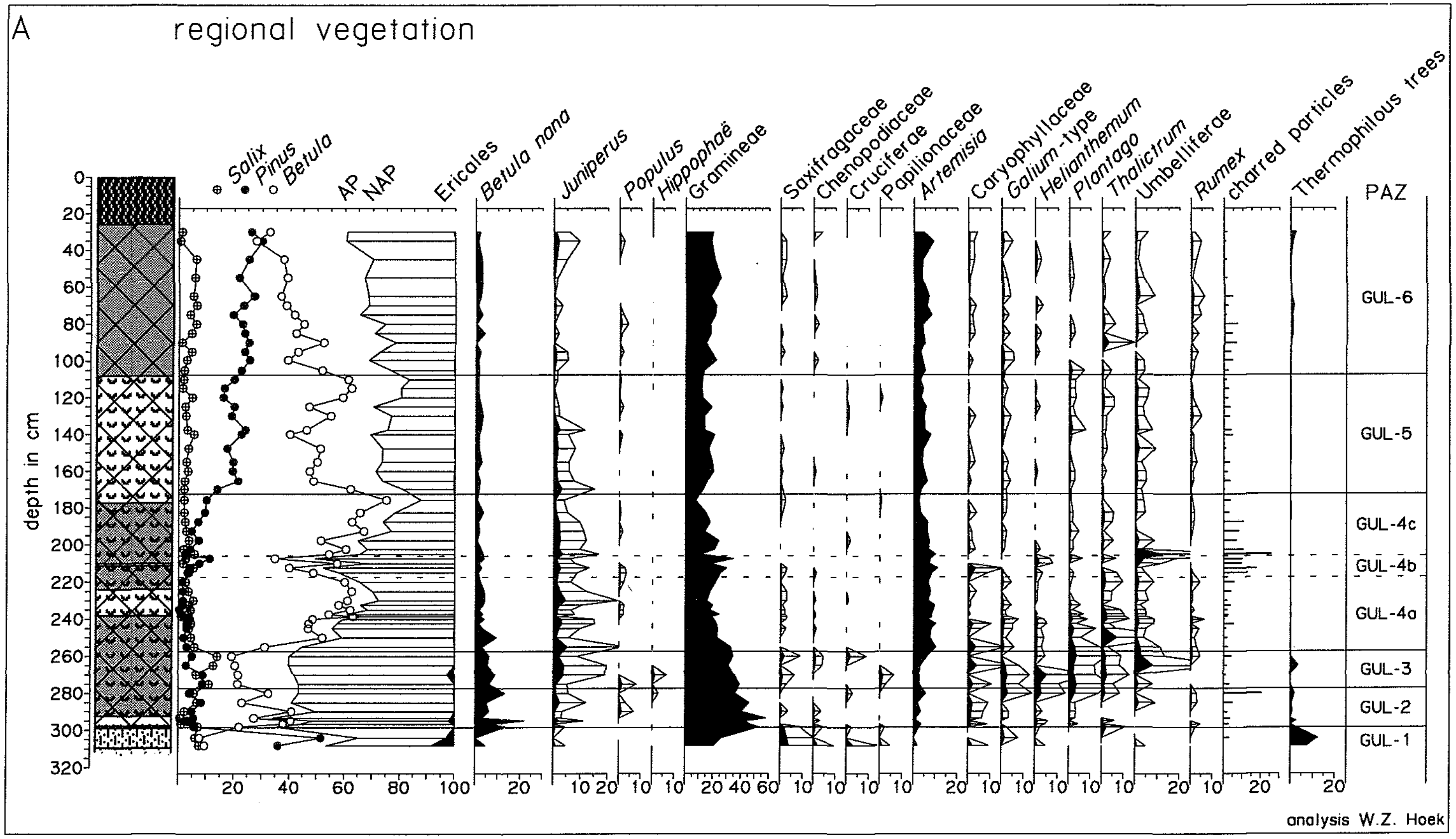

Figure 6.4 a) Regional pollen diagram Gulickshof I, for legend to the lithology see figure 6.3.

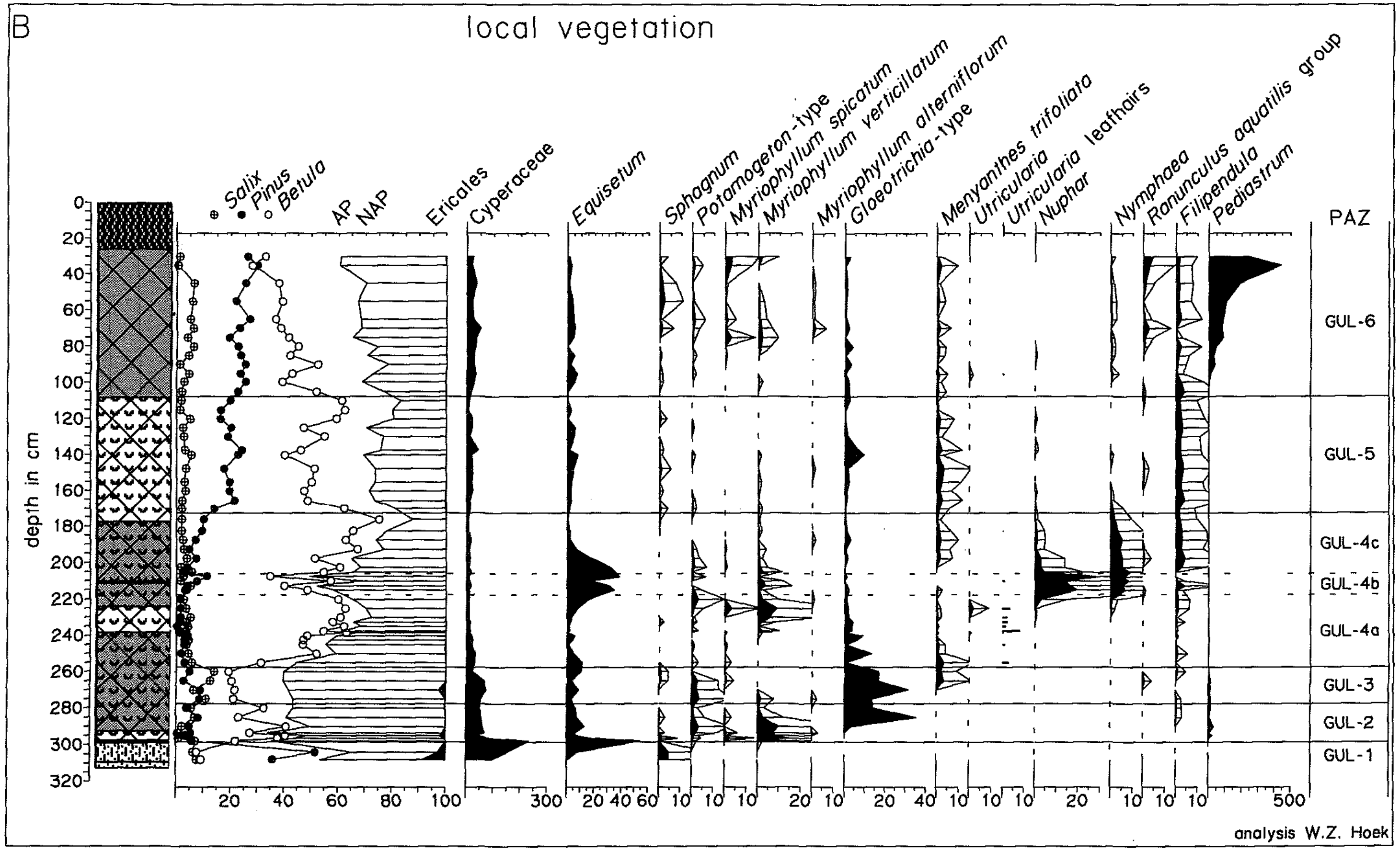

Figure 6.4 b) Local pollen diagram Gulickshof I, for legend to the lithology see figure 6.3.

age of 12,480 ± 90 BP. Zone GUL-2 compares with regional sub-zone 1b (12,450 - 12,100 BP), equivalent to the Bølling *sensu stricto* (van Geel *et al.*, 1989).

6.4.3 PAZ GUL-3 (277.5-257.5 cm)

The *Betula* tree pollen percentage decreases to 20% in favour of NAP (non arboreal pollen). *Juniperus* and *Salix* are present with higher values than during the preceding zone, 5 and 10% respectively. *Hippophaë* is present during this zone. The percentages of *Helianthemum*, *Plantago* and *Galium*-type are increasing. Towards the end of zone GUL-3 the percentages of *Salix* and Umbelliferae are rising, and Chenopodiaceae are present in higher values. The progressive vegetation development that started in the preceding zone hampered, or even a regressive development took place as expressed by a decline in the tree-birch curve. A simultaneous increase in *Juniperus* and *Salix*, which was presumably also locally present, suggests a return to a more open vegetation type. The changes in vegetation may be caused by regional drought, as suggested by van Geel and Kolstrup (1978), Kolstrup (1982), and Bohncke *et al.* (1987). Zone GUL-3 compares with regional sub-zone 1c (12,100 - 11,900 BP), equivalent to the Earlier Dryas (van Geel *et al.*, 1989).

6.4.4 PAZ GUL-4 (257.5-172.5 cm)

PAZ GUL-4 is characterized by relatively high *Betula* values, with continuously low *Pinus* values. This zone is sub-divided into three sub-zones based on a temporary decline in the *Betula* curve, and a concomitant brief increase of the *Pinus* pollen percentages.

PAZ GUL-4a (257.5-217.5 cm)
The basal spectrum of this zone coincides with a strong increase in *Betula* pollen percentages up to values between 50 and 60%, while *Juniperus* reaches its maximum value of 6%. The lower boundary of this zone reflects the development from an open shrub tundra into a boreal birch forest. During this period the Juniper belt passes over the site of registration during its migration northwards, as reflected by the increased values of *Juniperus*. Zone GUL-4a coincides with regional sub-zone 2a1 (11,900 - 11,500 BP).

PAZ GUL-4b (217.5-206 cm)
This sub-zone starts with a decrease in the *Betula* percentage to values around 40% in favour of NAP. The percentage of *Pinus* rises at the end of this zone towards values above 10%. Based on the decrease of AP together with an increase of NAP (mainly Gramineae and Umbelliferae), opening up of the regional boreal birch forest is assumed, possibly attributable to drought. Charred particles are abundant, fire may have caused the opening of the vegetation. On the other hand, drought may have induced fires in the region. The relatively close presence of pine forests is demonstrated by the increased influx of long-distance *Pinus* pollen during this period.

PAZ GUL-4c (206-172.5 cm)
With the start of zone GUL-4c the *Pinus* percentage drops to values below 5%. *Betula* percentages restore again to values of 70%. The boreal birch forests seem to have recovered during this period. Towards the end of this zone *Pinus* percentage rise again. Zone GUL-4b and GUL-4c coincide with regional sub-zone 2a2 (11,500 - 11,250 BP).

6.4.5 PAZ GUL-5 (172.5-107.5 cm)

At the base of this zone *Pinus* percentages exceed values of 20%. The *Betula* percentages decrease in value with around 20% and therefore the AP/NAP ratio does not change significantly. *Artemisia* relatively declines, implying that the area of open disturbed ground gradually diminishes, and vegetation cover is rather continuous. Zone GUL-5 coincides with regional sub-zone 2b (11,250 - 10,950 BP).

6.4.6 PAZ GUL-6 (107.5-25 cm)

A decrease in *Betula* percentages marks the start of this zone. *Betula* percentages fall from 60% to 35%. NAP percentages, comprising particularly Gramineae and *Artemisia* are favoured by this *Betula* decrease, *Salix* and *Pinus* percentages are slightly higher. Reworked pollen from thermophilous taxa such as *Corylus*, *Alnus* and *Quercus* is present in low values. The rising NAP values indicates an opening of the tree cover. The decrease in *Betula* pollen percentages implies that the regional area of birch forests contracted, which may have caused a relative increase of *Pinus* as a result of long-distance transport. Zone GUL 6 is equivalent to the first part of regional zone 3 (10,950 - 10,550 BP).

6.5 Chronostratigraphy

With respect to the general problems with radiocarbon dating of calcareous deposits in which terrestrial botanical remains are rare, biostratigraphical correlation has been used to obtain a stratigraphic framework. For the establishment of a stratigraphic framework the regional pollen zonation has been matched to the general Lateglacial and Early Holocene zonation scheme for The Netherlands (Hoek, 1997). Besides, the chronostratigraphy has been established by several AMS-datings. Furthermore, some conventional datings have been performed on different fractions from the calcareous gyttja deposits.

6.5.1 Biostratigraphical correlation

The regional zonation of the Gulickshof core has been correlated with the general Lateglacial zonation for The Netherlands (Hoek, 1997). This zonation is based on some 250 palynological records from The Netherlands, northern Belgium and western Germany. General trends in the AP/NAP-ratio as well as the main fluctuation in *Betula* and *Pinus* percentages constitute the essence of this zonation. Together with an evaluation of the available radiocarbon dates a time-stratigraphical framework has been established for a refined sub-division of the Lateglacial and Early Holocene in this region. The zonation for The Netherlands compares well to the regional zonation of the Gulickshof core, as has been shown in the previous section.

6.5.2 AMS-datings

From the palynologically investigated core samples were taken for AMS-dating (see table 6.2a). The mosslayer (298 cm), consisting of *Drepanocladus* and *Scorpidium* mosses, forms the base of the organic infill of the basin. The ^{14}C-sample from the mosslayer consisted of *Betula nana* leaves, and provided an age of 12,480 ± 90 BP (UtC-3196), which is in accordance with the generally adopted age of 12,500 BP for the beginning of organic accumulation in The Netherlands (van Geel *et al.*, 1989; Hoek, 1997). A sample from below this moss-layer yielded 12,330 ± 60 BP (GrA-5051), this age was obtained from a sample consisting of woody fragments which may be interpreted as roots. For Gulickshof, the age of 12,480 ± 90 BP marks the beginning of calcium carbonate precipitation. A sample consisting exclusively of *Betula* remains from the coarse detrital gyttja at 99-104 cm, a few cm above the transition from calcareous to organic gyttja, was dated at 10,800 ± 90 BP (GrA-4309) and marks the end of calcium carbonate precipitation. This age is in agreement with the expected age of around 10,900 BP based on biostratigraphical correlation with the general zonation for The Netherlands (see chapter 3).

Table 6.2 AMS (a) and conventional (b) radiocarbon dates from Gulickshof.

a AMS dates

lab.nr.	**depth in cm**	**age**	σ	$\delta^{13}C$	**material**
GrA-4309	99-104	10,800	90	- 30.24	*Betula* LF
GrA-5054 [1)]	110-115	11,550	70	- 26.07	*Betula* LF *Carex* F *Scirpus* F *Menyanthes* F
GrA-5047 [2)]	153-158	11,540	70	- 28.70	bulk organic fraction
GrA-4124	158-163	11,250	140	- 26.42	*Betula* LF *Salix* L *Carex* F *Menyanthes* F
GrA-5239	205-210	11,730	80	- 26.43	*Betula* LF *Carex* F *Menyanthes* F
GrA-5238	232-237	12,040	80	- 26.32	*Betula* LF *Carex* F *Menyanthes* F
GrA-5042	250-260	12,300	70	- 27.71	*Betula* LF *Carex* F *Scirpus* F *Menyanthes* F
GrA-5052 [1)]	280-285	16,040	90	- 25.03	*Betula* WLF *Carex* F
UtC-3196	298-299	12,480	90	- 29.4	*Betula nana* L
GrA-5051	300-305	12,330	60	- 28.67	*Betula* W (possible rootlets) *Juncus* F

material W=woody fragments, L=leaves, F=fruits/seeds
rejected samples: [1)] aged by possibly reworked material
[2)] aged by reservoir effect

b Conventional dates

lab.nr.	**depth in cm**	**age**	σ	$\delta^{13}C$	**material**
GrN-18458	153-158	11,590	60	- 28.70	bulk organic fraction
GrN-18459	153-158	11,610	70	+ 1.57	bulk $CaCO_3$ fraction
GrN-18457	158-163	11,690	90	+ 1.37	8-250μm pretreated
GrN-18455	227-232	12,520	140	- 36.42	bulk organic fraction
GrN-18456	227-232	13,060	60	- 8.32	bulk $CaCO_3$ fraction
GrN-18454	232-237	12,650	70	- 7.15	8-250μm pretreated

The following samples obtained from the calcareous gyttja all contained *Menyanthes trifoliata* seeds. A sample from the rise of the *Betula* curve between 250-260 cm yielded 12,300 ± 70 BP (GrA-5042) where 11,900 BP was expected based on biostratigraphical correlation. The maximum in the *Betula* curve expected round 11,700 BP gave an age of 12,040 ± 80 BP (GrA-5238). The dip in the *Betula* curve has been dated at 11,730 ± 80

BP (GrA-5239), while 11,500 BP was expected. A sample just above the *Pinus* rise, between 158-163 cm gave an age of 11,250 ± 140 BP (GrA-4124) where 11,200 BP was expected on biostratigraphical correlation. Although the sequence of the obtained AMS-dating results is consistent with depth, it appears that the difference between measured and expected age increases downwards, which might be explained by an ageing effect recorded by *Menyanthes* (but see 6.8).

With respect to the biostratigraphy and the sequence of radiocarbon dates, two macro fossil samples are apparently too old. The sample from 280-285 cm (GrA-5052, $\delta^{13}C$=-25.03) yielded 16,040 ± 90 BP where 12,100 BP was expected, while a sample from 110-115 cm (GrA-5054, $\delta^{13}C$=-26.07) yielded 11,550 ± 70 BP where 10,950 BP was expected. Both samples were obtained from levels which are considered as the onset of a climatic deterioration. The levels coincide with an increase of NAP in the pollen diagram, indicating that the vegetation cover became less dense. This may have resulted in reworking from older deposits.

6.5.3 Conventional datings

Samples for conventional ^{14}C-analysis were taken at two levels from which also AMS-datings are available (see table 6.2b). The purpose of the conventional datings was to get insight into the ageing effects of Lateglacial calcareous gyttjas. Törnqvist *et al.* (1992) showed that bulk samples from gyttjas and strongly clayey samples can yield ^{14}C ages up to 600 years older than AMS terrestrial macrofossil samples. Especially calcareous gyttjas are considered to record the ageing effects in full.

However, at Putbroek (Janssen and IJzermans-Lutgerhorst, 1973) a depression near Gulickshof with similar deposits, moss-remains from a calcareous gyttja, palynologically dated at the top of sub-zone 2a, yielded 11,195 ± 120 BP (GrN-5842) which is in accordance with the expected age of 11,250 BP. At Putbroek a conventional date from moss peat just above calcareous gyttja, yielded 10,890 ± 65 BP (GrN-6308). The AMS date on *Betula* remains from the corresponding stratigraphic level at Gulickshof mentioned above gave 10,800 ± 90 BP (GrA-4309), which is fairly consistent.

Conventional ^{14}C-datings from the top of pollen zone 2a1 yielded ages that are supposed to be too high as a result of enrichment of the lake water with ground water, combined with a reservoir effect. The results gave 12,520 ± 140 BP for the bulk organic fraction (GrN-18455) and 13,060 ± 60 BP for the bulk carbonate fraction (GrN-18456) at 227-232 cm. Especially this bulk carbonate sample appears to be over-aged. It is positioned just above the pretreated sample (GrN-18454) at 232-237 cm that yielded 12,650 ± 70 BP.

Conventional datings from zone 2b (153-158 cm) yielded ages that are supposed to be too high as a result of the reservoir effect. The results gave 11,590 ± 60 BP for the organic fraction (GrN-18458) and 11,610 ± 70 BP for the carbonate fraction (GrN-18459). An AMS dating from the same organic sample as the conventional date GrN-18458 yielded 11,540 ± 70 BP (GrA-5047), which is in full agreement with the above mentioned results. The pretreated sample positioned just below the above samples (158-163 cm) yielded 11,690 ± 90 BP (GrN-18457), which is also consistent with the above mentioned ages.

6.6 Local environmental changes

The interpretation of local environmental changes is based on geochemical, botanical and faunal evidence from the lake deposits.
Calcium carbonate precipitation in shallow lakes is primarily dependent on the carbonate content of the ground water feeding the lake. Calcium carbonate precipitates according to the carbonate equilibrium:

$$Ca^{2+} + 2\ HCO_3^- \rightleftharpoons CaCO_3 + CO_2 + H_2O$$

With a constant carbonate content of the ground water, the precipitation of calcium carbonate in lakes is related to both temperature and precipitation (rain/snow). Higher temperatures will cause:

a) more evaporation
b) induced submerged plant activity resulting in higher uptake of carbon- dioxide (CO_2) by plants from the lake water
c) a lower saturation-point of calcium carbonate in the lake water

These temperature related processes result in oversaturation and consequently the precipitation of calcium carbonate. Dilution of the lake water with rain or snow will cause a lower calcium carbonate precipitation. A curve of the changes in calcium carbonate content in time can therefore serve as a proxy-record for palaeotemperature/-precipitation (Stuiver, 1970; Siegenthaler and Eicher, 1986).

The analysis of the aquatic vegetation provides indications for changes in water level and therefore possible changes in effective precipitation. Furthermore, some aquatic species can be used as climate indicators (Iversen, 1973; Kolstrup, 1980; Isarin, 1997). Lateglacial temperature estimates based on Coleoptera and palaeobotanical information for the Netherlands are given by van Geel *et al.* (1989), Bohncke *et al.* (1987) and Bohncke (1993). It appears that local zone boundaries at Gulickshof coincide with regional zone boundaries described in the previous section.

On the basis of fresh-water mollusca, two zones can be recognized. Zone I from 220-295 cm and zone II from 163-220 cm. Zone I is characterized by species living on vegetation in the lake, while zone II shows a relative importance of species living on the lake floor. The zones can be sub-divided on the basis of the molluscan assemblages and the *Gastropoda/Bivalvia* and *Prosobranchia/Pulmonata* ratios. The zone and sub-zone boundaries coincide with the boundaries based on the regional vegetation development. Figure 6.5 shows the molluscan diagram, corresponding with the regional vegetation zones. For practical reasons, the regional zonation is used here for the discussion of the calcium carbonate curve, local vegetation development and malacodiagram. The calcium carbonate curve is presented in figure 6.8. Because the percentage of calcium carbonate is measured relative to the weight, only samples between 25 and 298 cm, with a minor amount of mineroclastic material can be compared.
In figure 6.6 the successive stages of the desintegration of the supposed ice-lens have been depicted.

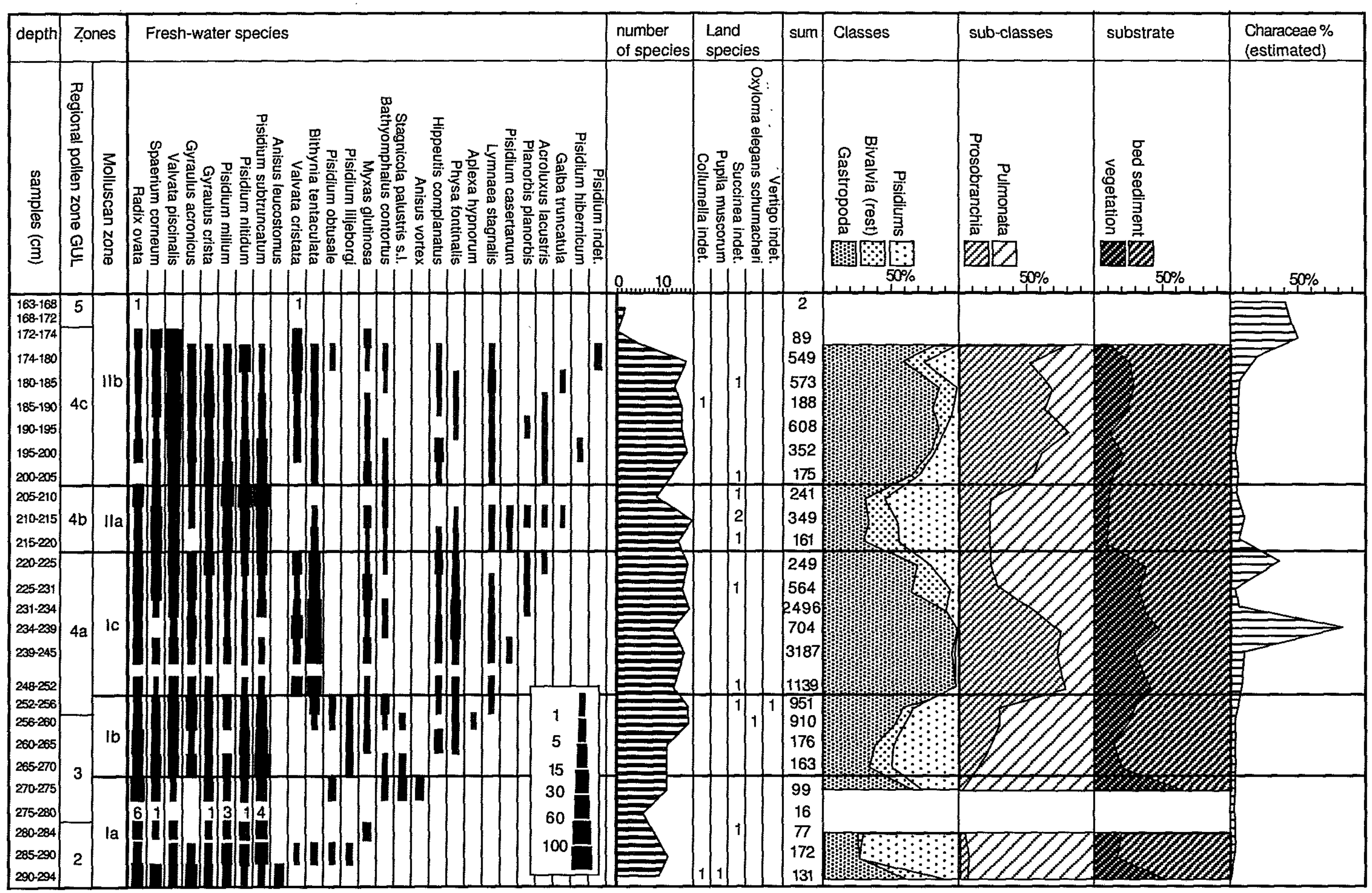

Figure 6.5 Molluscan diagram, analysis by T. Meijer.

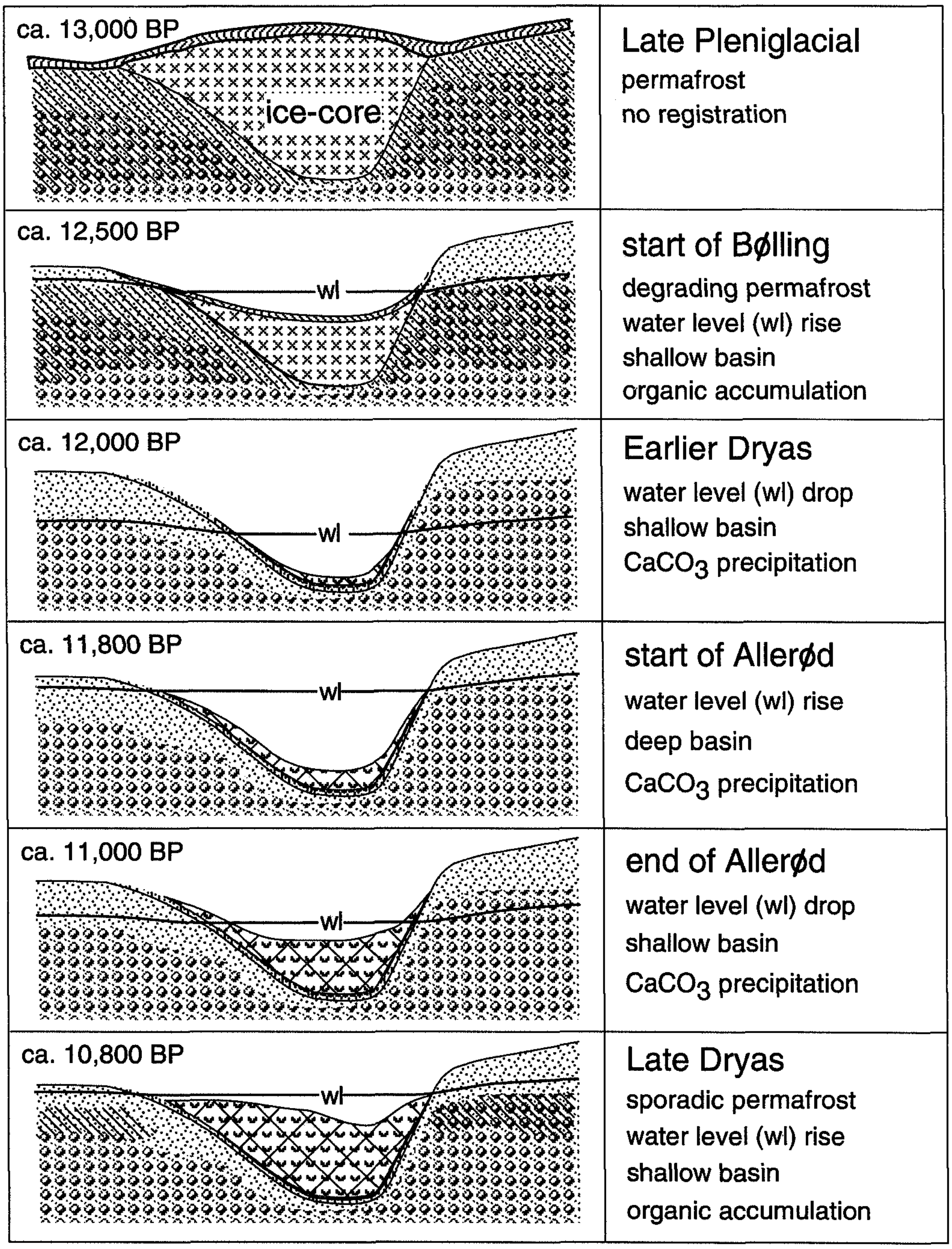

Figure 6.6 Development of the depression at Gulickshof, with main features, for legend to the lithology see figure 6.3.

6.6.1 12,900-12,450 BP (298.5-313 cm) PAZ GUL-1

Low calcium carbonate values around 10% in the sand and silty clays have been found, related to the nature of the deposits. During the deposition of this lithological unit the precipitation of calcium carbonate was outranged by the minerogenic input. The presence of a barren substratum intermingled with Saxifragaceae tussocks surrounding the basin implies a large mobility of sands and silts at that time. In the assumption that the depression was formed by the melting of an ice-core, the mass bulk of the material is most likely allochtonous and therefore cannot be compared to the authigenic limnic deposits. The local pollen assemblage shows a virtual absence of aquatic taxa partly as a result of pioneer conditions in the basin or an overall absence of open water. Cyperaceae and *Equisetum* are present in high percentages.
Molluscs were absent in this zone. Relic-permafrost presumably was still present in the beginning of this period and the ice-core started to desintegrate as a result of temperature rise.

6.6.2 12,450-12,100 BP (298.5-277.5 cm) PAZ GUL-2

Temperature reconstructions for the start of the Lateglacial in Usselo I (van Geel *et al.*, 1989) and Notsel (Bohncke *et al.*, 1987) indicate that mean July-temperature was already high (15-16°C). The increase in temperature induced in our view the initial melting of the ground-ice. As a result a shallow depression was formed in which a moss blanket could develop. By progressive melting of the ice-core the *Drepanocladus/Scorpidium* moss-layer with *Betula nana* shrubs submerged and a small lake was formed. The decrease in the percentages of Cyperaceae and *Equisetum* underlines the spread of open water. Stagnant water could not percolate into the subsoil beneath the basin as a result of the still present relic permafrost. The continuous lowering of the permafrost-table in the surroundings resulted in deeper percolation and solution of carbonates in the soil and transport to the basin. Together with the aquatic biological activity, this resulted in the start of calcium carbonate precipitation in the basin shortly after 12,500 BP. As the ground water became more saturated with carbonates and the biological activity increased, the precipitation of $CaCO_3$ increased from 30% in the moss-layer to 70% around 295 cm. Mesotrophic taxa were the main constituents of the aquatic vegetation (*Sphagnum*, *Potamogeton*-type, *Myriophyllum spicatum* and *Myriophyllum verticillatum*). Thus, although the melt-water from the surrounding permafrost was rich in carbonates, it contained relatively small amounts of nutrients.
Molluscs were present but not abundant. *Anisus leucostomus* has been found exclusively at the base of zone GUL-2. This species is characteristic for poor water conditions, subject to drying (Sparks, 1961). Pulmonata are relatively important during this zone.

6.6.3 12,100-11,900 BP (277.5-257.5 cm) PAZ GUL-3

According to van Geel *et al.* (1989), mean July-temperature was somewhat lower than the preceding time-interval but still high (14-16°C). The disappearance of the ground-ice which previously had acted as an impermeable layer caused a lowering of the ground water table and a subsequent lowering of the lake-level. The lake-level was lowered to such and extent that the lake became very shallow and its circumference declined. A decrease of the

$CaCO_3$ percentage to values around 20% might indicate that the basin was mainly fed with rain-water and snow melt-water. Among the aquatic taxa only *Potamogeton*-type and later on *Menyanthes trifoliata* occurred in reasonable percentages. Botryococcus is an important algae during this zone, emphasizing shallow water conditions. *Gloeotrichia*-type (blue algae) indicates the prevailing pioneer conditions in the basin. The pollengrains of *Potamogeton-type* possibly derive from *Triglochin maritima* from which seeds were present at this level. This halophytic plant must have grown on the emerging calcareous borders that surrounded the shallow lake after the lowering of the lake-level.
At the base of zone GUL-3 only few molluscs were present, which might be explained by the low water level. *Pisidium liljeborgi*, a typical Late Weichselian species (Ložek, 1986) and *Stagnicola palustris s.l.* were important during this zone. *Anisus vortex* has been found between 270 and 275 cm, while *Aplexa hypnorum* has been found exclusively between 256-260 cm. *Aplexa hypnorum* is a species that lives in poor water conditions, subject to drying (Sparks, 1961).

6.6.4 11,900-11,500 BP (257.5-217.5 cm) PAZ GUL-4a

According to van Geel *et al.* (1989), mean July-temperature remained constant (14-18°C). A rising ground water table as a result of recharge of the aquifers after the complete disappearance of the permafrost led towards a higher lake-level and a renewed increase in the calcium carbonate precipitation to values over 90% (230 cm). The aquatic succession continued with *Menyanthes trifoliata*, while the occurrence of *Utricularia vulgaris*-spines suggests mesotrophic to oligotrophic conditions. The rising water level is illustrated by the aquatic succession whereby *Menyanthes* is superceded by *Myriophyllum verticillatum* and *M. spicatum*. Nutrients, stored in the previously frozen substratum were mobilized by soil forming processes induced by the spreading boreal birch forests. The nutrients were transported by the ground water to the basin. This caused the aquatic succession to proceed with the appearance of more eutrophic species like *Nuphar (lutea and pumila)* and *Nymphaea (alba and candida)* at the end of this period.
In zone GUL-4a the highest number of molluscs has been found, most of them belonging to Gastropoda. *Bithynia tentaculata* is the most important species while *Valvata cristata*, characteristic for clean, slowly moving water and abundant aquatic plant growth (Sparks, 1961) was also frequently recorded in this sub-zone. *Planorbis planorbis*, indicative for abundant aquatic plant growth (Ložek, 1986) appeared during this zone. At the top of zone 4a, *Acroluxus lacustris*, a warmth-loving species (Ložek, 1986) appeared for the first time. Prosobranchia are relatively important during this zone.

6.6.5 11,500-11,250 BP (217.5-172.5 cm) PAZ GUL-4b/4c

The lake-level remained high which resulted in maximum values for *Nuphar* and *Nymphaea*, as well as *Equisetum* which was abundant at the margins of the lake. The decrease in calcium carbonate precipitation to values around 50% is a direct result of the large production of organic matter by Nymphaeaceae. Towards the end of this zone major changes in the palaeo-environment took place. Percentages of *Nuphar*, *Equisetum* and *Nymphaea* decreased, while *Menyanthes* and *Filipendula* became more important. A diminishing nutrient supply to the lake seems to be the most important factor for this change. This can only be attributed to a diminished ground water flow to the basin. The

ground water flow during this period may have been altered by river incision in the Maas valley (Kasse *et al.*, 1995). Calcium carbonate percentages increased quite abruptly towards the end of this period. This increase may be attributed to higher summer temperatures, which induced evaporation and subsequent lowering of the lake-level. Besides, a diminishing organic matter production in the lake will also have contributed to the relatively higher $CaCO_3$ values.
Bivalvia are abundant during zone GUL-4b and like in zone GUL-2, Pulmonata are relatively important. *Bithynia tentaculata* decreased strongly, while *Valvata cristata* was completely absent. *Succinea* land snails were present in all samples from this zone. Gastropods are the most important molluscs during zone GUL-4c. *Valvata piscinalis* has been recorded most frequently, while *Valvata cristata* was again present. Remarkable is the reduction in molluscs towards the end of this zone although Characeae persisted.

6.6.6 11,250-10,950 BP (172.5-107.5 cm) PAZ GUL-5

A subtle change in minimum mean July-temperature after 11,300 BP to 13°C occurred, while the maximum estimate indicates 18°C (van Geel *et al.*, 1989). The major changes occurring in the minimum mean winter temperature, were mainly responsible for an increased annual temperature range. The ground water and lake-level changes that were initiated in the previous zone continued. The aquatic succession stopped, *Nuphar* and *Nymphaea* almost disappeared and the vegetation developed towards a more oligotraphentous type with *Menyanthes* and *Sphagnum*. A temporary water level drop in the basin may be the main reason for the disappearance of the aquatic taxa, while also fresh water molluscs disappeared. The effect of oversaturation diminished, and calcium carbonate precipitation from now on was controlled by temperature and availability of carbonates. This resulted in a gradual decrease in calcium carbonate precipitation from 90% to 60%. A possible source for the calcium carbonate were the calcareous borders of the now shallow lake, from which carbonates were dissolved and transported to the deeper part of the basin. A final increase in the calcium carbonate precipitation towards the end of this period suggests a small short-lasting temperature increase.

6.6.7 10,950-10,550 BP (107.5-25 cm) PAZ GUL-6

With a major drop in mean July-temperature to values possibly as low as 10-11°C (van Geel *et al.*, 1989) the precipitation of calcium carbonate ceased. Calcium carbonate percentages decrease from 10% at the base of this zone to 0% at 80 cm. In this period deep seasonal frost and even sporadic permafrost possibly re-occurred in the area (Bohncke *et al.*, 1993). This may have caused a rise of the artificial ground water table. The combined effect of diminished calcareous upwelling and the decrease of the July-temperature resulted in the decrease of the calcium carbonate precipitation. In the aquatic vegetation *Pediastrum* was present in high values. *Nymphaea* returned in low percentages, and are together with members of the *Ranunculus aquatilis* group an indication of a return to deeper water conditions. This zone correlates with the first part of the Late Dryas.
During the second phase of the Late Dryas, lowering of the water table and presumably generally drier conditions (Bohncke *et al.*, 1993) caused the accumulation in the basin to stop. This lowering may also be a result of the disappearance of the ground-ice during this period.

6.7 Stable isotopes and climate

Oxygen isotope curves from lakes reflect environmental changes. Curves from Swiss and French lake deposits show variations which coincide with climatic fluctuations as recorded in Greenland ice-cores (e.g. Lotter *et al.*, 1992; Eicher, 1987). For The Netherlands, the Lateglacial Gulickshof sequence provides the first oxygen isotope record. Kolstrup and Buchardt (1982) investigated a Lateglacial lake deposit at Grænge, Denmark, and demonstrated that in the carbonate fraction a substantial amount of detrital carbonate was present. This resulted in a deviant $\delta^{18}O$ record compared to for instance the Swiss isotope records (Eicher, 1987). From lake Gosciaz, Poland, a record from the Late Allerød to the Preboreal could be obtained (Goslar *et al.*, 1993). In Belgium some cores have been analysed by Kiden *et al.* (in preparation).
Important for a reliable isotope signal in terms of environmental change is that the sediments must contain a sufficient amount of carbonate formed in the lake itself. Hammarlund and Buchardt (1996) were able to prove that Late Cretaceous coccolith taxa in the sediment contributed to the ^{18}O enrichment during the Late Dryas. Thus, in the deposit in Denmark allochtonous carbonate particles deposited into the basin during especially the Late Dryas stadial hampered the establishment of a reliable isotope curve for north-western Europe (Kolstrup and Buchardt, 1982; Hammarlund and Buchardt, 1996).

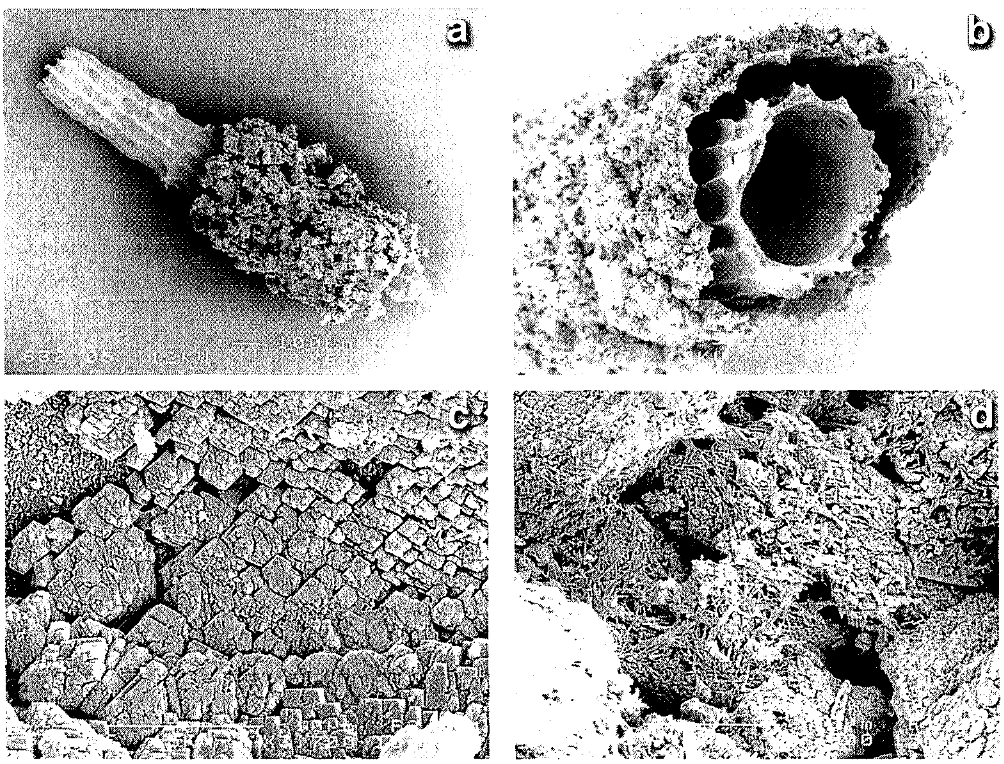

Figure 6.7 Scanning Electron Microscope pictures of *Chara globularis* encrustrations.
a) calcareous encrustration with inner coat and cortex (x65).
b) cross section through inner coat and cortex (x150).
c) inner coat structure (x3,700).
d) cortex structure (x3,300).

In the Gulickshof basin, calcium carbonate is supposed to have been precipitated chemically, mainly as a result of biological withdrawal of CO_2 for assimilation of submerged plants. Most of the calcium carbonate was precipitated inside and around Characeae as calcareous encrustrations, and is abundant in the deposits in the presence of small stems. The calcium carbonate is expected to be authigenic, which is supported by SEM-images from Characeae encrustrations (*Chara globularis*), showing the cristaline structure and the absence of allochtonous calcium carbonate particles (figure 6.7).

Our analyses of pretreated samples yielded typical isotopically lighter values, between 0.34‰ and 2.32‰ lower than the untreated bulk samples. Similar deviations between untreated and pretreated samples are decribed by Siegenthaler and Eicher (1986) who suggest to use untreated samples. In figure 6.8, the results from the pretreated samples are presented as bars within the isotope curves of the untreated material.

Table 6.3 $\delta^{13}C$ values obtained from conventional radiocarbon dating on carbonates and $\delta^{18}O/\delta^{13}C$ analysis on different carbonate fractions.

depth in cm	**sample**	**material**	$\delta^{18}O$	$\delta^{13}C$
155	gh1/33	bulk	-6.28	+1.54
153-158	GrN-18459	bulk		+1.57
160	gh1/32	bulk	-5.79	+1.61
158-163	GrN-18457	8-250μm		+1.37
230	gh1/18	bulk	-6.96	-8.31
227-232	GrN-18456	bulk		-8.32
235	gh1/17	bulk	-7.11	-6.72
235	gh1/17	8-63μm	-7.58	-7.13
235	gh1/17	Shells	-5.98	-8.64
235	gh1/17	*Chara* encrustrations	-7.73	-7.88
232-237	GrN-18454	8-250μm		-7.15

From sample gh1/17 at 235 cm with the lowest $\delta^{18}O$ value in the section, calcareous Characeae encrustrations and shell fragments were sorted under a binocular microscope, crushed and measured separately. The results are listed in table 6.3. The calcareous Characeae encrustrations yielded the lightest values for $\delta^{18}O$, while the sieved fraction also yielded isotopically lighter values than the bulk carbonate samples. The shell fragments gave the heaviest values which contributed to the deviation between the Characeae and bulk samples.

Stuiver (1970) states that the oxygen isotope ratio can be used as a climatic indicator for fresh-water environments, an average increase of 0.70‰ in oxygen isotope ratio meaning a 1°C temperature increase. This temperature estimation can only be achieved if there had been a good exchange between atmosphere and water in the basin. Before drawing climatological conclusions one has to be sure that there was a sufficient water-atmosphere interaction.

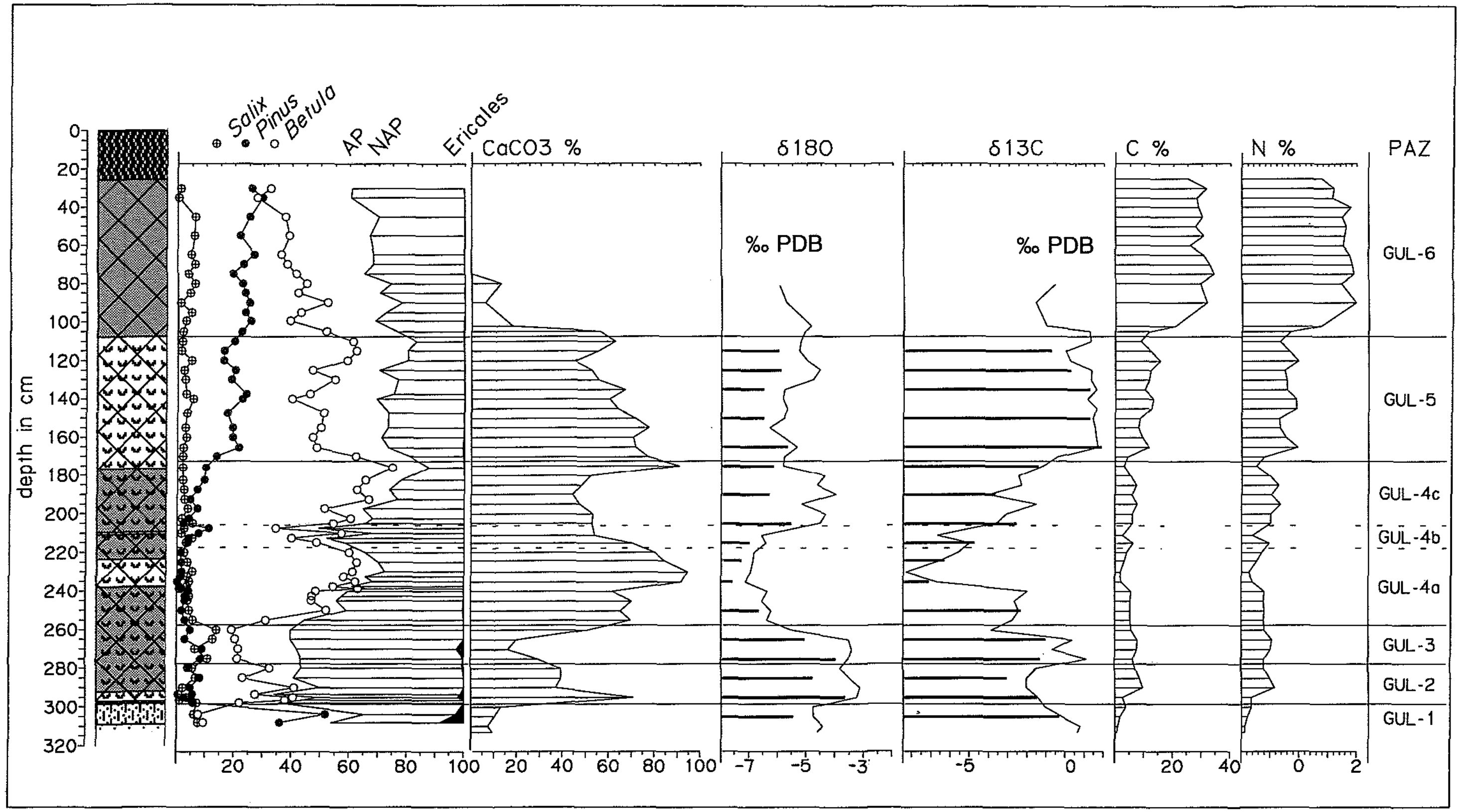

Figure 6.8 Calcium carbonate and isotope curves from the Gulickshof core, for legend to the lithology see figure 6.3.

The interpretation of the carbon isotope signal is, however, more difficult. $\delta^{13}C$ values from -12‰ to -10‰ are supposed to originate from ground water carbonates in The Netherlands (Mook, 1970), while values around +2‰ suggest a longer residence time in the lake, and mixing with the atmosphere or enrichment as a result of biological activity (Siegenthaler and Eicher, 1986). $\delta^{13}C$ values above 0‰ indicate a good mixing with the atmosphere and $\delta^{18}O$ values from the same sample will be in equilibrium with the atmosphere, while samples with $\delta^{13}C$ values around -10‰ will provide a ground water biased $\delta^{18}O$ value.

From this perspective, the $\delta^{13}C$-curve in figure 6.8 shows an important ground water influx during PAZ GUL-4 (257.5-177.5 cm) and a minor influence during PAZ GUL-2 (298.5-277.5 cm). Typically atmospheric signatures are recorded during PAZ GUL-1 (313-298.5 cm), GUL-3 (277.5-257.5 cm) and GUL-5 (177.5-107.5 cm). The $\delta^{13}C$ curve can in this way be used as additional information for interpreting the oxygen isotope curve.
The $\delta^{18}O$-record can therefore be considered as a good palaeo-climatic signal in especially zones GUL-1 (12,950-12,450 BP), GUL-3 (12,100-11,900 BP) and GUL-5 (11,250-10,950 BP). For zones GUL-2 (12,450-12,100 BP) and in particular GUL-4 (11,900-11,250 BP), palaeo-temperature estimates will not be reliable, as a result of a substantial ground water contribution to the signal.
The $\delta^{18}O$-curve, presented in figure 6.8 shows in general a decrease from -3‰ in zone GUL-2 to -6‰ at the end of zone GUL-5. Low values, less than -7‰ prevail during sub-zones GUL-4a and GUL-4b. Those low values are not attributable to changes in temperature but are a result of the increased inflow of carbonate rich ground water into the basin.
The minimum average Juli-temperature decreased from 15°C to 13°C between the start of the Bølling to the end of the Allerød interstadial (van Geel *et al.*, 1989). A decrease in the $\delta^{18}O$-curve of 3‰ over the same time-span (GUL-1 to GUL-5) coincides with a temperature decrease of 2°C, according to Stuiver (1970).

6.8 Discussion and concluding remarks

The regional vegetation development, with the fluctuations within the Allerød compares well to the general Lateglacial vegetation development for The Netherlands (Hoek, 1997). The AMS-dating results on *Betula* macro-fossils coincide with the expected dates based on the regional biostratigraphy, whereas samples containing *Menyanthes* seeds yield ages some hundred years older than expected on biostratigraphical grounds. Therefore, the chronostratigraphy of the Gulickshof record is largely based on biostratigraphical correlation. Based on the AMS-dating results from selected macrofossils in this study an ageing effect is assumed as a result of gaseous exchange between *Menyanthes* and the strong calcareous substratum in the Gulickshof basin. The use of *Menyanthes* or other riparian species growing in calcareous basins therefore has to be discouraged for AMS-dating.

The present study shows the changes in nutrient status and ground water flow during the last Glacial-Interglacial transition. Only circumstantial evidence is available for the final degradation of the permafrost following the Upper Pleniglacial cold maximum. The mosslayer at the basis of the depression at Gulickshof marks the beginning of the water table rise as a consequence of the warming up after the Weichselian Pleniglacial and is dated around 12,500 BP. This indicates the onset of the disappearance of permafrost in this area. Changes in water conditions since that time have been recorded by means of local vegetation, molluscan fauna, calcium carbonate and stable isotopes. It appears that the Earlier Dryas drought, dated between 12,100 and 11,900 BP may be a result of the effective disappearance of permafrost and subsequent regional lowering of the ground water table. The higher lake level and increased amount of nutrients led to a flourishing aquatic vegetation between 11,900 and 11,250 BP. Between 11,250 and 10,950 BP the aquatic succession stopped and the regional situation became drier in general, possibly as a result of climatic change. With the onset of the Late Dryas climatic cooling around 10,950 BP, calcium carbonate precipitation came to an end, possibly as a result of the re-establishment of permafrost. The deposition in the Gulickshof basin ceased during the second part of the Late Dryas. The incision of the river Meuse is supposed to have caused the displacement of the ground water exfiltration zone towards lower terrace levels since then.

In the Gulickshof basin, calcium carbonate is supposed to have been precipitated chemically and thus contamination by allochtonous carbonate particles can be neglected. Nevertheless, a deviant $\delta^{18}O$-record compared to for instance the Swiss isotope records (Eicher, 1987; Lotter *et al.*, 1992) was obtained. With the help of the $\delta^{13}C$-curve increased ground water influx could be recognized, which caused the strong deviations in the $\delta^{18}O$-curve particularly between 11,900 and 11,250 BP.
The relation between the $\delta^{13}C$-curve and the amount of ground water influx can not only be used for the interpretation of the $\delta^{18}O$-curve but also gives information about the possible ageing effects in ^{14}C-dating results. The ageing effects in the conventional ^{14}C-datings from the calcium carbonate rich level (90%) at the top of pollen zone 2a1 are obviously related to the high amount of carbonates derived from ground water superimposed on the reservoir effect of the lake. The lowest $\delta^{13}C$ values in the section of -8.32‰ at 227-232 cm and -7.15‰ at 232-237 cm are indicative for a major ground water influence. The weighted mean average, according to the method described by Mook and Streurman (1983), of the carbonate samples yielded 12,886 ± 46 BP. The conventional dating for the organic fraction gave 12,520 ± 140 BP. An AMS dating from the same stratigraphic level gave 12,040 ± 80 BP, whereas 11,700 BP was expected by biostratigraphy. The ages for these levels indicate for the organic fraction an ageing effect between 500 and 800 radiocarbon years and for the calcium carbonate fraction between 800 and 1,200 radiocarbon years relative to the AMS and expected age, respectively.
The ageing effects in the calcium carbonate rich level (80%) in pollen zone 2b can be ascribed predominantly to the reservoir effect in the lake. The $\delta^{13}C$ values for the carbonates of +1.57‰ and +1.37‰ indicate a minor influence of ground water. The weighted mean average of the carbonate samples yielded 11,640 ± 55 BP, while the weighted mean average of the conventional and AMS age for the bulk organic fraction yielded 11,569 ± 46 BP. An AMS dating on selected macrofossils from the same level gave 11,250 ± 140 BP, where 11,200 BP was expected on biostratigraphical grounds. The age difference between the organic fraction and the calcium carbonate fraction is almost negligible. Thus, the reservoir effect in the Gulickshof basin can be estimated between 300 and 450 radiocarbon years.

7 ENVIRONMENTAL AND CLIMATE CHANGES IN THE NETHERLANDS DURING THE LATEGLACIAL AND EARLY HOLOCENE

(together with S.J.P. Bohncke)

7.1 Introduction

Deposits ascribed to the Weichselian Lateglacial period in The Netherlands have already been analyzed palynologically by Florschütz in 1939, but the first proper lacustrine pollen record was compiled by van der Hammen (1949). His arguments for a Lateglacial age of the lake sediments, beside its stratigraphical position, were based on parallels in the vegetational development with the records produced by Iversen in Denmark. The Allerød period pre-eminently was characterized as a period of landscape stability, during which little clastic material was supplied to the lake leading to the deposition of a pure detrital gyttja. Besides the Allerød interstadial also the Bølling interstadial was proved to be present in the lake sediments. Both interstadials were separated by a supposedly cold stadial called the Earlier Dryas. Implications with respect to the Lateglacial climate were drawn and a refined subdivision of the Lateglacial was proposed following the one that Iversen (1947) developed (see chapter 2).

Gradually a picture of the Lateglacial vegetation development in relation to climate and landscape development emerged (van der Hammen, 1951). This idea was further refined with the investigations of van der Hammen en Wijmstra (1971) in the Dinkel valley (figure 7.1). During the digging of the New Dinkel canal in the late 60-ies many profiles in which Middle and Upper Pleniglacial, Lateglacial and Holocene sediments were exposed, could be studied. This study provided a comprehensive picture of the lithostratigraphic and vegetational development over the period involved. Figure 4.5 shows the lithostratigraphic subdivision of the Lateglacial aeolian deposits.

Since then many Lateglacial pollen records from different localities and different lithologies have been analyzed. The introduction of Coleoptera analyses (Coope and Brophy, 1972) greatly altered the established view on the climatic development during the Weichselian Lateglacial. Lags in the vegetational development in response to episodes of swift climatic improvement became apparent. The combination of different, both quantitative and qualitative palaeoclimate indicators, such as Coleoptera, botany and geomorphology can give supplemental information about climate change. Quantitative palaeoclimatic indicators such as oxygen-isotopes and Coleoptera have rarely been investigated in The Netherlands; in Usselo I (van Geel *et al.*, 1989) and Notsel (Bohncke *et al.*, 1987) palaeotemperature records were constructed based on fossil Coleoptera in combination with botanical evidence.
The Lateglacial calcareous gyttja deposits at Gulickshof (chapter 6) gave the opportunity to study Lateglacial environmental changes with different methods. Pollen, plant macro-fossils, fresh water mollusca, stable isotopes and geo-chemical analyses provided a combined evidence that was fitted into the Lateglacial chronostratigraphy with the help of AMS-dates on terrestrial plant macro-fossils.

The role of the rivers during this specific time-interval drew much attention and clarified many of the geomorphological processes that took place (e.g. Vandenberghe *et al.*, 1987; Kasse *et al.*, 1995).

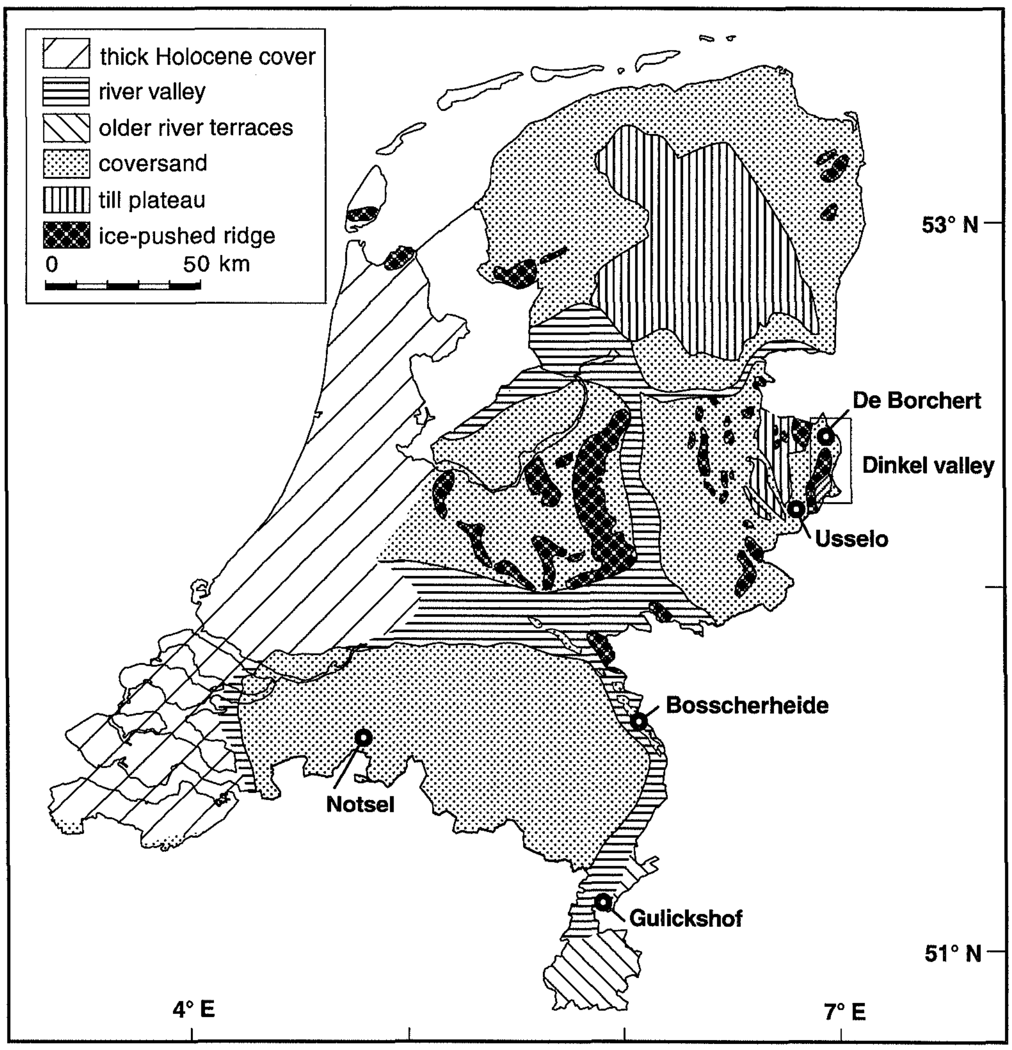

Figure 7.1 Map of The Netherlands, depicting sites and areas discussed in the text and in which the main geomorphological elements in the landscape are indicated.

A critical review of available radiocarbon dates from over 100 pollen diagrams has led to a chronostratigraphical framework for the general Lateglacial and Early Holocene vegetation development in The Netherlands and direct surroundings (chapter 3). The chronological framework made it possible to compare vegetation development with other proxy records.

In order to discuss the Lateglacial time-interval effectively one needs to begin with the period immediately preceding the Lateglacial to demonstrate the uniqueness of this transitional period.

7.2 The beginning of the Weichselian Lateglacial

It has been demonstrated in many exposures that during the maximum cold of the Upper Pleniglacial (Stage 2, $\delta^{18}O$) an arctic soil was formed often associated with periglacial structures such as cryoturbations, frost fissures, frost cracks and sand wedges. Deflation processes had truncated the old surface level and its periglacial structures and left behind a desert pavement, a thin pebble layer called the Beuningen gravel bed, which is a recurrent level in many exposures with deposits bracketing this time-interval. An exact date for this Beuningen complex is, in the absence of datable material, not possible, but it is generally assumed that it should be placed somewhere between 22,000 and 14,000 BP (Kolstrup, 1980). Climatic conditions were extremely cold and dry and vegetation was almost absent. Subsequently, deposition of coversands prevailed (Older Coversand II, figure 4.5). This unit is deposited as sand sheets, horizontally-bedded and laminated by alternating sand and loamy sand layers. The absence of periglacial structures, although some frost fissures and micro 'drop soil' structures are present, points to a period of climatic improvement and permafrost is believed to have disappeared before 14,000 BP (but see below). Sedimentary structures that indicate running water are rare. It is believed that there was a general shortage in effective precipitation and this may well have been a limiting factor for the spreading of shrubs and trees.
The conditions for preservation of organic material were poor, which resulted in a lack of radiocarbon dates from this period. The start of Lateglacial organic accumulation at favourable localities in The Netherlands is set at 12,900 BP, represented by organic accumulations restricted to thin layers of humus or organic debris in predominantly minerogenic substrates (chapter 3). Continuous organic accumulation in The Netherlands did not begin before 12,500 BP. An approximate date for the termination of the Older Coversand II is given in van Geel *et al.* (1989) and centers around 12,400 BP.

7.3 The Weichselian Lateglacial

7.3.1 The Earliest Dryas, sub-zone 1a (12,900 - 12,450 BP)

The beginning of the Lateglacial in The Netherlands is by definition placed at a level where in the palynological records *Artemisia* starts to rise (van der Hammen, 1951). This rise is assumed to indicate a first sign of the climatic improvement shown by palaeobotanical data. It can be placed shortly after 12,900 BP (van Geel *et al.*, 1989, figure 7.2). Lithostratigraphically the Older Coversand II continues into the Lateglacial and correlates at least in part with the relatively warm and tree-less pre Bølling *sensu stricto* or Earliest Dryas period. Important heliophilous herbaceous taxa encountered in the pollen records of this period are *Helianthemum*, *Rumex acetosa-acetosella*, *Polemonium*, *Thalictrum*, *Artemisia*, *Plantago major-media* and Chenopodiaceae. Summer temperature reconstructions can best be made on the presence of aquatic species, but the basins appear to have a low nutrient status except for the presence of calcium and therefore seem to lack critical species, which happen to prefer more nutrient rich conditions. This low nutrient status may be explained by assuming the presence of relic ice in the subsoils. Therefore all nutrients that entered the basins derived from precipitation and from melt-water released by the disintegrating relic permafrost. The topsoil, which had been exposed to the surface for some time during which most nutrients were leached, did not supply much nutrients. Moreover the low nutrient status at the beginning of the Lateglacial has

been demonstrated by the occurrence of Cyanobacteria of the *Gloeotrichia*-type. These Cyanobacteria played an important role in the fixing of nitrogen, preparing in this way suitable conditions for settlement of other plant taxa (van Geel *et al.*, 1989).
River activity was limited over this period and only traces of braided river sediment were found, indicating a large bed load and strong seasonality in the discharge of the rivers probably due to snow melt in spring and early summer.
In the absence of sensible plant indicator species temperature reconstructions for this period are based on fossil beetle (Coleoptera) faunas. At Usselo (van Geel *et al.*, 1989) reconstructed mean summer temperatures were between 15 and 20°C.

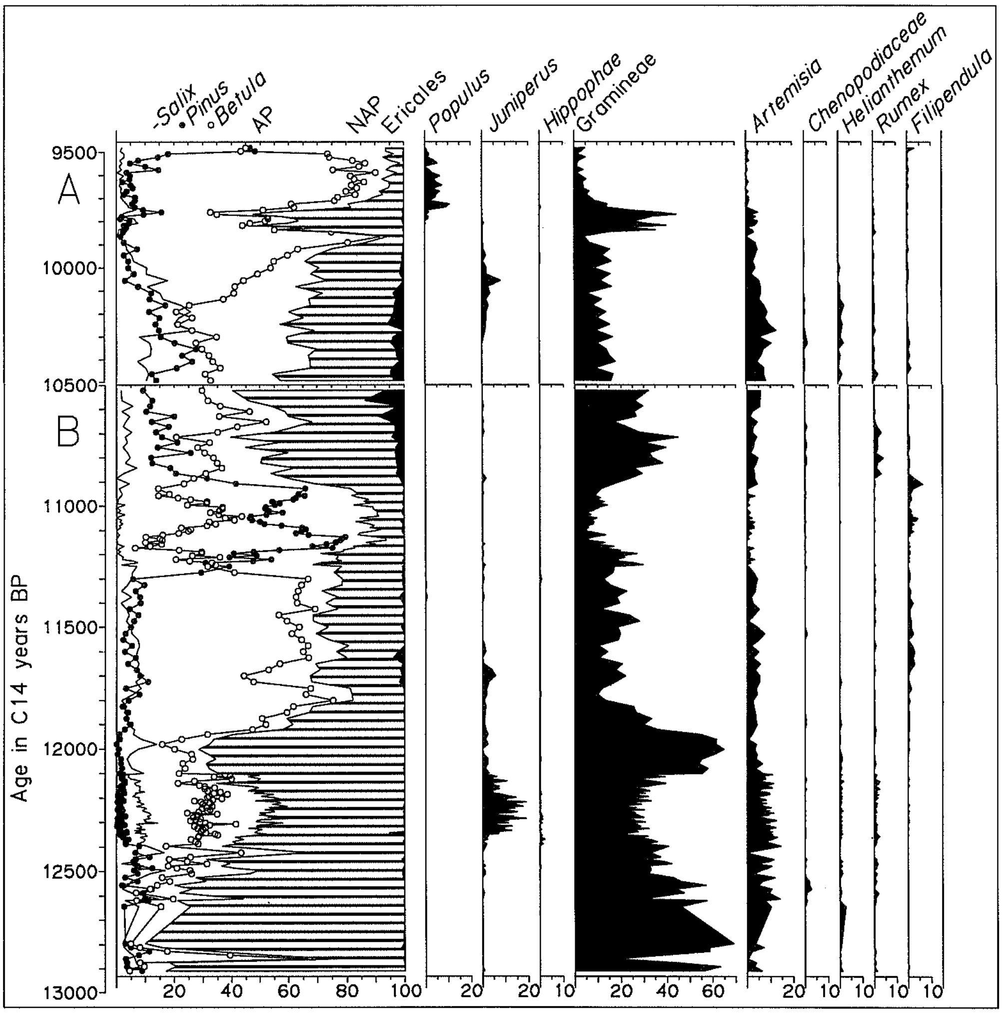

Figure 7.2 Compilation of two pollendiagrams from Twente (eastern Netherlands). A is sequence de Borchert, redrawn after van Geel *et al.* (1981) and B is sequence Usselo I, redrawn after van Geel *et al.* (1989). A selection of taxa is presented. Both diagrams are plotted against an uncalibrated ^{14}C time scale.

7.3.2 The Bølling, sub-zone 1b (12,450 - 12,100 BP)

Although it is often assumed that permafrost had disappeared directly after the Beuningen Complex, evidence from ice-cored terrains and from the infilling of pingo remnants demonstrate that relic ground ice was only starting to disappear shortly after 12,500 BP. The release of water from segregation ice and relic permafrost in combination with an increase in effective precipitation induced the spread of wet localities and the spread of a more continuous vegetation cover. Simultaneously the substratum became fixed and aeolian activity ceased (see figure 7.3).

Evidence from research into the fluvial dynamics demonstrates that rivers over this time interval experienced a gradual transition from braided multi-channel flows through an intermittent system with only a few active channels to meandering, single channel systems, with a low sinuosity (figure 7.3). A progressive vegetational development from an open heliophilous herb vegetation passing through a stage with dwarf willow and dwarf birches and culminating in a *Betula pubescens* open boreal forest is registered in the pollen records. The spread of the tree birches is defined as the base of the Bølling *sensu stricto*. Mean July-temperatures dropped from between 15 and 20°C to between 15 and 16°C (Bohncke *et al.*, 1987 and van Geel *et al.*, 1989).

7.3.3 The Earlier Dryas, sub-zone 1c (12,100 - 11,900 BP)

Palynologically the period following the Bølling is characterized by a temporary decline in the *Betula* pollen curve and an increase in heliophilous herbs. Lithostratigraphically deposition of coversands started to prevail, the so called Younger Coversand I (see figure 4.5).
Previously, in the absence of Coleoptera analyses that could provide evidence about mean temperatures of the warmest month, estimates of summer temperatures were based on fluctuations in the tree species especially birch. A decline in birch was at first thought to be an indication of a decline in the summer temperatures to around 10°C. The introduction of Coleoptera data for summer temperature reconstructions did not suggest such a dramatic decline. A mean July-temperature range between 14 and 16°C was deduced on the Coleoptera fauna. Since there is an absence of periglacial structures that can be assigned to this period (but see van Geel *et al.*, 1989) mean January-temperatures may well have declined but, would not have been lower than -15°C.

Alternative ideas were developed to explain the changes in environmental conditions during the Earlier Dryas. The introduction of the concept of a climatologically dry episode then was thought to be the explanation for the regional birch decline (van Geel and Kolstrup, 1978). This idea was supported by palaeohydrological data from lake sediments (Bohncke and Wijmstra, 1988) in which this phase was characterized by a temporary low in the lake levels and it was believed that the environmental changes, registered during this interval could be ascribed to drought and consequently by a decline in precipitation. Later when the fluvial response to the climatic events during the Lateglacial became clear, the idea developed that river incision and the formation of meandering systems, that happened to take place at around this time, might well have caused a temporary decline in the ground water level in areas adjacent to rivers (Bohncke *et al.*, 1993; Kasse *et al.*, 1995).

Recent evidence seems to point to the role of relic permafrost, which apparently did not disappear completely during the Earliest Dryas period (chapter 6). A scrutiny of the occurrence of aquatic taxa against time demonstrated that the nutrient status of lakes changed drastically at the transition from Bølling to Allerød and pointed to changes in the hydrological system. The nutrient input during the early Allerød must have come from the previously frozen subsoil and only became available in the early Allerød period. The timing of this event can only be explained by assuming that relic permafrost was still present until that period and that access to the nutrients that were stored in the deeper subsoil could be released by the delayed melting of it. A minimum depth of the permafrost, that was established during the maximum cold in the Upper Pleniglacial was estimated on the base of the depth of pingo remnants and attributed to at least 17 meters in the northern Netherlands (de Gans, 1981).
Another argument for a relatively late disappearance of ground ice is the fact that the earliest registration in pingo remnants on palynological grounds started approximately during the Bølling, eg. 12,400 BP. This implies that melting of the ice-cores of pingos was not yet completed prior to this date and maybe definite melting occurred sometime after this date.
The final melting of relic ice and the establishment of the hydrological cell is probably a decisive process that determined the main processes in the landscape at that time. This process had set in concomitantly with the temperature increase at the start of the Lateglacial, but the final melting can be seen as a delayed response to this climatic amelioration.
As a consequence of the complete disappearance of ground ice the precipitation was no longer hampered to infiltrate into the aquifers and more freely drained soils established. This must have had a major effect on the regional vegetation, which must have experienced dry soil conditions and for a large part died back. A more open heliophilous vegetation re-established. In the pollen records of this period the retrogressive vegetational development is demonstrated by the temporary decline in the AP (Arboreal Pollen) and a concomitant rise in the NAP (Non Arboreal Pollen). Especially *Betula pubescens* is very sensitive for such dry environmental conditions. *Hippohaë rhamnoides* on the contrary seems to thrive well in these dry, well drained soils.
The aquifers may from now on have been able to nourish the basins and the $\delta^{13}C$ decrease, registered in the calcareous gyttja at Gulickshof (chapter 6), is ascribed to this phenomenon. Nutrients that were stored in the subsoil were mobilized and water that entered the basin thus considerably improved the nutrient status of basins. In this way the right conditions were created for more nutrient requiring aquatic taxa to participate in the hydrosere.

It cannot be excluded that the fluvial system reacted to the process of final melting of relic permafrost with an incision and started to form a one channel meandering system. Another argument for river incision is the spread of the vegetation cover since the start of the Bølling *sensu stricto* that fixed the substratum and considerable contributed to a decline in sediment load. As a consequence energy, previously used for sediment transport, was now used for incision.
River incision and dry soil conditions were matched by increased aeolian activity and led to the formation of inland dunes and coversands. Lithostatigraphically, these mineroclastic deposits are called Younger Coversand I (see figures 4.5 and 7.3). The Younger Coversands lack the alternation of sand and silty sand laminae, which is characteristic for the Older Coversands.

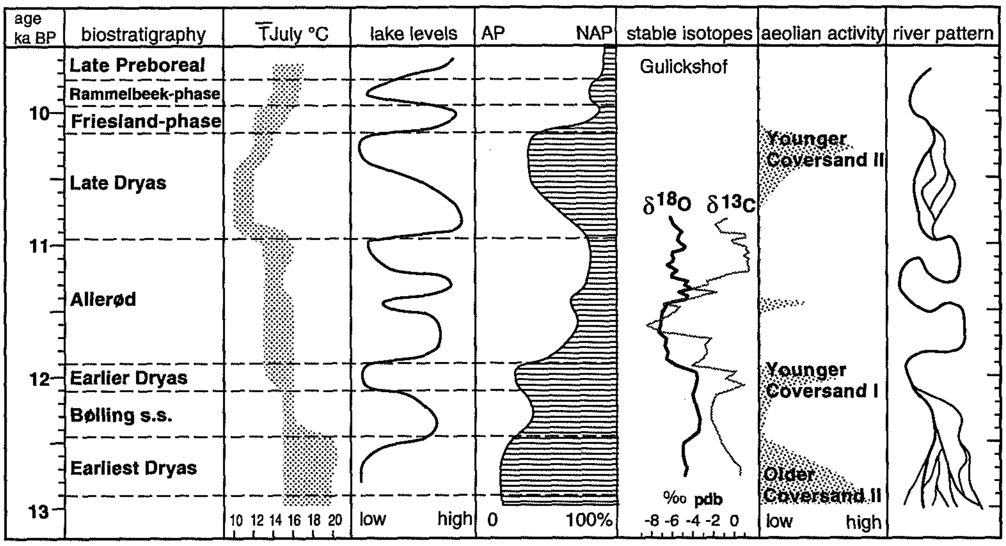

Figure 7.3 Schematic overview of the principal environmental changes plotted against an uncalibrated ^{14}C time scale.

To resume, the final disintegration of relic permafrost and the reaction of the fluvial system by incision culminated in a short episode during which soil conditions became dry. Subsequently, a recharge of the aquifers took place and the ground water table gradually rose. The depressions now filled with nutrient rich ground water and many nutrient requiring aquatics appear in the pollen record. Among them taxa are found that can be used as plant indicator species for the reconstruction of mean summer temperatures.
The spread of wet localities in the landscape enabled birch to regain its position in the regional vegetation. The start of the second birch increase is taken as the start of the Allerød period (see figure 7.2).

7.3.4 The Allerød, zone 2 (11,900 - 10,950 BP)

Palaeohydrological studies reveal the return to high lake-levels (Bohncke and Wijmstra, 1988) and increased fluvial discharges (Bohncke and Vandenberghe, 1991) early in the Allerød period (see figure 7.3). It can not be excluded that the palaeohydrological changes can partly be attributed to increased effective precipitation or a significant winter snow cover.

The re-establishment of wet soil conditions contributed to the renewed spread of tree-birches, preceded by a phase of *Juniperus* expansion. Aeolian activity curtailed and stable soil conditions may be deduced for this episode. The presence of *Typha angustifolia, Nymphaea alba* and *Nuphar lutea* facilitate the reconstruction of a mean July-temperature of at least 14°C, while Coleoptera assemblages provided a temperature range of between 13 and 16°C. Mean January-temperatures are estimated in the range between -16 and +6°C. The supply of old ground water to the calcareous gyttja at Gulickshof greatly hampers the temperature reconstructions on the basis of the $^{16}O/^{18}O$ ratio for the early Allerød period (chapter 6). During this relatively stable episode soil profiles developed, that in some cases have been preserved in the lithological sequence. This palaeosol is referred to as the 'Usselo' soil after its type locality in Usselo.

There seems to be one distinct episode interrupting this phase of stability. Directly prior to ca. 11,300 BP some sites in the fluvial realm register an increase in overbank deposits and hydroseral successions show a renewed increase in open water (Bohncke *et al.*, 1993). A more peaked fluvial discharge for this period may be deduced. Simultaneously, there seems evidence for a further decline in mean July- and January-temperatures for this time interval are considered to have declined to between -13 and -16°C, the lower limit of the mean January-temperature range inferred from Coleoptera data for The Netherlands. With summer temperatures unchanged these temperature conditions would allow for deep seasonal frost and a more intensive action of the freeze-thaw cycle. This temperature regime would have promoted unstable soil conditions causing an increase in sediment load in the fluvial systems, which can be traced as overbank deposits. Besides, the presence of segregation ice will have hampered precipitation to infiltrate into the soil in the early spring, and in return will have caused increased run-off and peak discharges in early spring and inundations of older terraces and deposition of sediment load on these older terraces.

Contrarily to what was assumed until recently, the *Pinus* increase around 11,250 BP does not represent the Lateglacial climatic optimum but instead seems a reaction to increased continentality in the climate. The Lateglacial pine dominated forests of the Central European province of the Eurosiberian region rapidly shifted west-wards as can be seen in the *Pinus* rise in the palynological records. Evidently, *Pinus* replaced to a large extend the previously existing boreal *Betula* forests.
During this *Pinus*-phase of the Allerød the lacustrine basins reach another low in the lake-levels (see figure 7.3). At the end of the Allerød the pine forests were not in equilibrium with the then existing climate conditions and for a large part died back. The many dead pine trees became prone to forest fires and burnt down which caused the Usselo soil of Allerød age frequently to contain charcoal particles.

7.3.5 The Late Dryas, zone 3 (10,950 - 10,150 BP)

At the transition of the Allerød to the Late Dryas a major and abrupt change in the climate occurred, also referred to as the Younger Dryas event. The registered changes were induced by a sudden southward shift of the Oceanic Polar front in the Atlantic Ocean that produced a considerable decline in summer temperatures on the continents in the Northern hemisphere. Depression tracks will have reached their largest activity close to the position of the Oceanic Polar front and frequently must have passed over The Netherlands (Renssen, 1997).

In The Netherlands conditions approached those of permafrost environments (chapter 4). Many fossil periglacial structures assigned to the beginning of this episode confirm the extremity of the climate. At Bosscherheide, periglacial loading structures have been described by Bohncke *et al.* (1993). The dark, highly organic Allerød soil, originally formed in a more or less horizontal position, and the underlying fluvial sands and loams have been deformed as a result of periglacial loading early in the Younger Dryas. It is not a surprise

that these climatic conditions had a far reaching effect on the landscape. Based on Coleoptera evidence, mean July-temperatures fell from between 15 and 18°C to between 10 and 11°C while mean January-temperatures ranged from between -16 and +6°C to between -15 and -7°C (Bohncke *et al.*, 1987). Hence, mean annual temperatures declined to below -1°C, probably between -2 and -5°C, and allowed for the development of discontinuous permafrost, which is supported by fossil periglacial phenomena (Isarin, 1997).
The regressive vegetational development that started with a rapid decline in the pine forest continued with a return to a patch-work of forest stands and shrub tundra with *Betula nana, Salix reticulata*, and *Salix herbacea* and in the northern Netherlands with *Empetrum* heath. This vegetation type can be described as forest tundra (Chernov, 1985). Heliophilous herbs became relatively more frequent indicating an opening up of the preceding boreal forest.

In combination with the return to almost periglacial conditions and the disappearance of a large part of the boreal forest, effective precipitation will have increased and concomitantly infiltration into the ground will have declined. Together with the large-scale availability of sediment due to unstable soil conditions the water surplus led to drastic changes in the fluvial regimes. Multi-channel braided river systems were re-established (figure 7.3). The finds of bractae of *Salix* spp. in the flood sediments without any leaves suggests peak discharges due to snow melt in early summer that caused large-scale floodings and the formation of large shallow lakes adjacent to the large rivers. These lakes were inhabited by species such as *Potamogeton,* Ranunculaceae subgenus *Batrachium, Hippuris vulgaris, Myriophyllum spicatum, Myriophyllum alterniflorum, Menyanthes trifoliata, Equisetum palustris, Sparganium* species and pleurocarpe mosses.

This period came to an end when half way during the Late Dryas ca. 10,550 BP, the mean annual temperature rose to above -1°C and discontinuous permafrost conditions were terminated. Periglacial structures can only be found in the lower part of the Late Dryas sediments. Partly because these sediments were humid enough for segregation ice to develop. Segregation ice disappeared again and water could freely percolate into the subsoil. Dry soil conditions re-established probably enlarged by a decline in the precipitation.
There seems to be a somewhat different vegetational development between the southern and the northern part of The Netherlands. In the southern Netherlands an increase in boreal pine forest is registered while in the northern Netherlands a dwarf shrub tundra with *Empetrum* heath, intermingled with dry herb communities persisted (chapter 5; Hoek, 1997). In dune slacks pollen of *Ephedra distachya* and *Ephedra fragilis* occur.
From about 10,550 BP river activity ceased and only functioned during the period of snow melt in late spring/early summer. The periodically-emerging river beds formed the source for the aeolian sediments that accumulated as large parabolic river dunes under predominantly SW prevailing winds. These aeolian sediments in lithostratigraphical terms belong to the Younger Coversands II (figures 4.5 and 7.3), which were deposited during the Late Dryas.
The sequence at Bosscherheide (Bohncke *et al.*, 1993) evidently demonstrates that the aeolian deposition is limited to the second part of the Late Dryas and that aeolian deposition is preceded by a wet and cold phase in the climatic history.

7.4 The termination of the Weichselian Lateglacial

7.4.1 The Early Holocene, zones 4 and 5 (10,150 - 9,150 BP)

It has been demonstrated above that already during the second half of the Late Dryas there appears to be some indications for a slight climatic improvement. In the absence of a protecting snow cover, conditions may still have been very severe for plant-life. Biostratigraphically the Late Dryas terminates with a distinct increase in *Betula pubescens* preceded by a *Juniperus* maximum (see figure 7.2). Quite often *Filipendula* shows a simultaneous increase. Mean July-temperatures are likely to have restored to the Lateglacial interstadial values (15 to 17°C). An assessment of the mean January-temperatures is more difficult to give. Taking into account the configuration of North West Europe with the sea-level being still low, one would expect a rather continental climate.
The spread of both *Betula pubescens* and *Filipendula* argue for a spread of wet localities. This is confirmed in the lake-level record where a temporary rise in the water level is registered. The increase in vegetation cover in return will have caused a cessation of the bulk of the aeolian activity. In sequence de Borchert (van Geel *et al.*, 1981) a date of 10,150 BP is given for this event. The spread of wet localities only occurs locally where due to favourable conditions accumulation of organic sediment takes place. In other localities the early Holocene is represented by a hiatus.

The vegetation development was not unidirectional. Localities where the early Holocene is present quite often register, after an initial spread of the tree birch, a short lasting interval during which a decline in the tree birch occurs and a spread in the grasses takes place (see figure 7.2).
This revertance in the vegetational development has been recognized in pollen records in The Netherlands (van der Hammen and Wijmstra, 1971), N.W. Germany (Behre, 1966) and Denmark (Iversen, 1973). Behre (1966, 1967) described the fluctuations in the *Betula* curve in the Preboreal and introduced the name Friesland-oscillation for the first climate improvement. Van der Hammen (1971) proposed for the period of *Betula* increase the term Friesland-phase and for the episode of higher percentages of herbs the term Rammelbeek-phase. Behre (1978) referred to this interval with higher herb percentages as the Youngest Dryas. Later, van Geel *et al.* (1981) demonstrated that the registered changes could not only be ascribed to a decline in winter temperatures but that to some extent a palaeohydrological aspect played a role. The drier conditions might be a result of a lowering of the ground water table as a result of fluvial incision that occurred during this period as well. Van Geel *et al.* (1981) dated the Friesland-phase between 10,150 and 9,850 BP, while the episode during which grasses prevailed was dated between 9,850 and 9,750 BP (Rammelbeek-phase). The beginning of this episode can be positioned around 9,950 BP, based on a compilation of radiocarbon dates (chapter 3).
The successive period of the early Holocene, during which both *Betula pubescens* and *Betula pendula* spread followed by a *Pinus* increase around 9,500 BP is called the Late Preboreal (9,750 - 9,150 BP). Remarkable is the role of *Populus tremula* during the onset of the Late Preboreal period. The appearance of the light requiring *Populus* underlines the openness of the vegetation at this stage in the vegetation development.

7.4.2 Holocene deciduous forests

Both mean summer and winter temperatures rose relatively rapidly in the period since 9,750 (Zagwijn, 1994). So far plant taxa that played part in the Lateglacial vegetation and in the Early Holocene vegetation are the same. With the appearance of *Corylus avellana* at ca. 9,150 BP a completely new element in the vegetation was introduced. Thermophilous trees as *Quercus, Tilia, Ulmus* and *Alnus* appeared subsequently. By 8,600 BP pollen records in The Netherlands provide evidence for winter temperatures above -2°C when *Hedera helix* appears in the pollen assemblages (van Geel et al., 1981; Zagwijn, 1994). The appearance of these species is a definite sign that the continental climate conditions, that determined the Lateglacial environmental conditions had terminated.

7.5 Further research

Although in recent years the knowledge of the Lateglacial climatic history has greatly improved in The Netherlands there remains an absolute necessity to tie our data in with the now existing data based on ice-cores, laminated lake sediments and glacier movements. For this purpose we should look for calcareous sediments that can provide an independent climate signal like a $\delta^{18}O$ curve. AMS ^{14}C dates based on terrestrial plant remains will in the future greatly improve our time control on the different climate signals stored in Lateglacial sediments. Wiggle Match Dating, and the extension of the ^{14}C-calibration back in time will improve the correlation with other stratigraphies. For the clastic sediments we need to know how much time there is included in the Coversand deposits. Especially we need a better time-control towards the beginning of the Lateglacial which is included in the Older Coversand II. This can probably be reached by applying termoluminescense (OSL) techniques on these sediments. An absolute blank in our knowledge is the duration of the polar desert period that has produced the Beuningen gravel bed. A timing of this event will greatly improve our time-stratigraphical scheme of the Upper Pleniglacial and start of the Lateglacial. The lack of iso-chronic marker horizons like tephra layers in The Netherlands is a great disadvantage and in future research an emphasis will be put on the search for the Laacher See tephra of which up to now in situ traces have not been found. This only underlines the evidence that plumes of this volcanic outburst did not reach The Netherlands.

SUMMARY

PALAEOGEOGRAPHY OF LATEGLACIAL VEGETATIONS: ASPECTS OF LATEGLACIAL VEGETATION, ABIOTIC LANDSCAPE, AND CLIMATE IN THE NETHERLANDS

Introduction

The Weichselian Lateglacial marks the transition from the cold Weichselian Late Pleniglacial to the warmer Holocene and can be dated approximately between 13,000 and 10,000 ^{14}C-years before present (BP). During this period climate changed rapidly, as did vegetation and the abiotic landscape.
The modelling of vegetation, environment and climate in this dynamic period is rather difficult, not only because modern analogues are absent. By the evaluation of a large number of palynological sections from a variety of abiotic landscape types, a better insight can be given in the relationships between palaeovegetation and environmental factors. A palaeogeographical approach offers the opportunity to consider the relationships in time and space.

Lateglacial vegetation development

The Lateglacial vegetation development in The Netherlands, which is the main subject of this study, can be described as follows:
At the end of the cold Weichselian Late Pleniglacial (13,000 BP), a sparse vegetation cover existed comprising Gramineae (grasses), Cyperaceae (sedges) and some dwarf shrubs, while many places were altogether bare. From around 12,900 BP species-rich herbaceous plant communities and dwarf bushes developed as a result of a rise in temperature; scattered *Betula* (birch) trees were present in the open vegetation type. During this phase which is characterized by a rather open vegetation type, a period with an expansion of birch, the so-called Bølling interstadial occurred.
In the Allerød interstadial starting round 11,900 BP, rather open *Betula* and *Pinus* (pine) woods dominated and the so called Usselo soil with charcoal particles was formed.
The development to a more dense vegetation cover was interrupted by the colder Late Dryas stadial at 10,950 BP, when the area of *Pinus* woods contracted considerably in favour of herbaceous plant communities. *Empetrum* (crowberry) is a characteristic plant for the second phase of the Late Dryas in particularly the northern Netherlands.
At the start of the Holocene around 10,150 BP *Betula* woods and later *Pinus* woods again developed as a result of temperature rise. The development of deciduous forests started around 9,000 BP with thermophilous trees as *Corylus* (hazel), *Quercus* (oak), *Tilia* (lime), *Ulmus* (elm) and *Alnus* (alder) which appeared subsequently.

The Lateglacial vegetation development as described in our neighbouring countries is largely comparable to that in the Netherlands except for some parts of north-western Germany. However, the Meiendorf interstadial as described in several German studies as the first sign of rising temperature before the Bølling interstadial is in our opinion equivalent to the Bølling *sensu stricto* (sub-zone 1b), whereas the Bølling-interstadial in the German studies is equivalent to the first part of the Allerød (sub-zone 2a1).

In The Netherlands over 400 palynological sections, covering a part or the whole of the Weichselian Lateglacial, have been investigated by several institutes in the last decades. For the compilation of the data from over 250 pollen diagrams, use was made of the European Pollen Database structure. For the construction of pollen diagrams a uniform pollen sum was used to calculate percentages. In this pollen sum only regional terrestrial taxa are included. Aquatics and riparian taxa including Cyperaceae, as well as spores and reworked thermophilous tree pollen, were excluded from the pollen sum.
For correlation of the pollen diagrams, a regional zonation has been constructed. Most important in the zonation are the shifts in *Betula* and *Pinus* percentages. Shifts in the percentages of Arboreal Pollen (AP), Non Arboreal Pollen (NAP), *Salix* (willow), *Juniperus* (juniper), *Populus* (aspen), *Artemisia* (wormwood) and *Empetrum* were also used for the zonation.

Vegetation and climate

For analysis of the relationship between vegetation, climate and the abiotic landscape, the chronologies need to be synchronous. Radiocarbon dated shifts, together with a critical evaluation of dating results presented by different authors formed the basis for the attachment of the above mentioned palynological zonation to the ^{14}C time-scale. With the help of 239 radiocarbon dates derived from 102 pollen diagrams from The Netherlands, Northern Belgium and Western Germany the regional vegetation development has been attached to the uncalibrated radiocarbon time-scale. It appears that single or older radiocarbon dates can still be very useful if critically evaluated and considered in a regional perspective.
Palynological changes which can be attributed to episodes of climatic deterioration are recorded at 12,100, 11,500, 10,950 and 9,950 BP. The chronological framework made it possible to compare vegetation development with other proxy records. Climatic oscillations recorded in oxygen-isotope records from Swiss lake sediments and the Greenland ice-cores are also reflected in the regional vegetation development in The Netherlands.

Vegetation and landscape

The Lateglacial landscape is a landscape with a changing geomorphology and vegetation. During the Weichselian Lateglacial geomorphological processes were active but were not as intense as during the preceding Weichselian Pleniglacial. Geomorphological processes related to permafrost that were active at the end of the Pleniglacial disappeared as a result of changes in climate towards the Holocene.
For The Netherlands in general five landscape types can be distinguished with their specific processes, responsible for the changes in geomorphology and vegetation. These landscape types are: ice-pushed-, till-, loess-, coversand-, and river landscape.
A crucial component responsible for geomorphological processes such as erosion, dune formation, river incision, or changes in river pattern is the erodibility of the substratum. Vegetation fixated the sub-soil, initiated soil-formation and thus stabilized the substratum. It is demonstrated that the changes in the abiotic landscape can be better understood in combination with changes in vegetation.

The vegetational development of the Weichselian Lateglacial in The Netherlands is determined firstly by the large-scale changes in climate and in the second place by local variations in lithology, geomorphology and hydrology. Pollen diagrams from different areas, embracing the same time-stratigraphical interval, often show clear variations in vegetation history, which can not be explained on climatological grounds alone.

Iso-pollen maps of main taxa were constructed for different time-windows within the Weichselian Lateglacial. The dense network of palynological observation sites in The Netherlands permitted the drafting of high-resolution iso-pollen maps of the period considered. A clear relationship can be recognized between the iso-pollen patterns and the landscape type.

Case-study Gulickshof

Environmental changes were studied on Lateglacial calcareous gyttja deposits at Gulickshof, southern Netherlands. Pollen, plant macro-fossils, fresh-water mollusca, stable isotopes ($\delta^{18}O$ and $\delta^{13}C$) and geo-chemical analyses were performed and the combined evidence was put into the chronostratigraphic framework based on regional biostratigraphy and AMS radiocarbon dating. The pollen diagram shows a vegetation development from the Bølling interstadial into the Late Dryas stadial within 2.9 meters of lacustrine deposits. The well dated, multi-proxy environmental record can be considered as a standard for this region. Clear palynological changes within the Allerød can be recognized, which can be correlated with the regional vegetation development in The Netherlands. Early in the Allerød, at around 11,900 BP, the composition of aquatic taxa and stable isotopes of CaCO3 changed significantly. These changes are interpreted to reflect fluctuations in groundwater level caused by the definite melting of ground ice and associated changes in the nutrient availability.

The existence of relic permafrost in the early Lateglacial is presumed to be an important factor in the changes in (ground) water-level and vegetation. Definite melting of ground ice has major implications for water-level changes and nutrient supply to the water bodies. Nutrients stored in the deeper lying sediments became available by melting the permafrost. This is reflected in the composition of aquatic taxa and stable isotopes. It is demonstrated that this moment is reached early in the Allerød interstadial at around 11,900 BP.

Conclusions

Regional trends in Lateglacial and Early Holocene vegetation development can be recognized in pollen diagrams from different landscape types. These general trends are considered to be synchronous over The Netherlands and thus related to changes in climate, while anomalies reflect other, local environmental changes.

Beside changes in vegetation, changes in the abiotic landscape occurred during the investigated period, particularly in the coversand and river landscape. These changes can can be better understood if the vegetation development, being an important factor in geomorphological processes, is known.

The presence and definite melting of the permafrost just before the Allerød interstadial will have been of major importance for the development of the landscape as a whole.

It is possible with a palaeogeographical approach to distinguish more clearly between climate and other abiotic agencies of the environment which affected vegetational development.

SAMENVATTING

PALAEOGEOGRAFIE VAN LAATGLACIALE VEGETATIES: ASPECTEN VAN DE LAATGLACIALE EN VROEG-HOLOCENE VEGETATIE, HET ABIOTISCH LANDSCHAP EN HET KLIMAAT IN NEDERLAND

Introductie

Het Weichselien Laatglaciaal vormt de overgangsfase tussen het koude Weichselien Pleniglaciaal en het warmere Holoceen, een periode die valt tussen ongeveer 13.000 en 10.000 ^{14}C-jaren voor heden (BP). Tijdens deze periode veranderde naast het klimaat ook de vegetatie en het abiotisch landschap. De trend van een stijgende temperatuur werd tenminste eenmaal onderbroken door een koudere periode, het Late Dryas-stadiaal. Het modeleren van vegetatie, milieu en klimaat in dit dynamische tijdsbestek brengt bijzondere problemen met zich mee. Met name is het moeilijk om voldoende actuele analogen van deze specifieke omstandigheden te vinden. Door pollendiagrammen met een zo groot mogelijke variatie van palaeomilieus bij het onderzoek te betrekken konden relaties tussen de palaeovegetatie en verschillende milieu-factoren (klimaat, lithologie, geomorfologische situering) worden gelegd. Het in verband brengen van de afzonderlijke waarnemingspunten in ruimte en tijd, een palaeogeografische benadering, bied extra mogelijkheden tot interpretatie van de vegetatie-ontwikkeling in het Laatglaciaal.

Laatglaciale vegetatie-ontwikkeling

De laatglaciale vegetatie-ontwikkeling in Nederland, het hoofd-onderwerp van dit onderzoek, kan als volgt worden samengevat:
Aan het einde van het Pleniglaciaal (13.000 BP) was er een geringe vegetatie-bedekking die bestond uit voornamelijk grassen, zegges en enkele dwerg-struiken. Grote delen waren echter nog onbegroeid. Vanaf ongeveer 12,900 BP kon zich, als gevolg van de temperatuurstijging, een soortenrijke kruidenvegetatie met groepjes struiken vormen. Verspreid kwamen ook berkenbomen voor. Tijdens deze fase met een relatief open vegetatie was er een periode met meer berkenbomen, het zogenaamde Bølling-interstadiaal.
Tijdens het Allerød-interstadiaal, dat begon rond 11.900 BP, werd de vegetatie steeds dichter en bestond voor een groot deel uit open berken- en later ook dennenbossen. De vorming van de zogenaamde Usselo-bodem vond in deze periode plaats.
De natuurlijke ontwikkeling naar een dichter woud werd rond 10.950 BP onderbroken door het koude Late Dryas-stadiaal. De dennenbossen stierven voor een groot deel af en een meer open kruidenrijke vegetatie kon zich opnieuw ontwikkelen, in Noord Nederland werd deze vegetatie gekenmerkt door het veelvuldig voorkomen van kraaiheide.
Aan het begin van het Holoceen, rond 10.150 BP, konden de bossen zich opnieuw uitbreiden als gevolg van de stijgende temperatuur. Eerst bestonden deze bossen voornamelijk uit berken en later uit dennen. Vanaf ongeveer 9.000 BP vormden zich uitgestrekte loofwouden met hazelaar, eik, linde, iep en els, bomen die opeenvolgend deel uit gaan maken van de Nederlandse flora.

De laatglaciale vegetatie-ontwikkeling zoals deze beschreven is in de ons omringende landen is grotendeels vergelijkbaar met de ontwikkeling in Nederland, zoals hierboven beschreven. In delen van Noordwest Duitsland wordt echter ook nog het zogenaamde Meiendorf-interstadiaal beschreven. Dit zou de eerste reactie van de vegetatie op de temperatuurstijging voor het Bølling interstadiaal vertegenwoordigen. Bij nadere beschouwing blijkt dat het Meiendorf-interstadiaal overeenkomt met wat in Nederland het Bølling-interstadiaal (1b) wordt genoemd. Het Bølling-interstadiaal in de Duitse studies komt dan overeen met het eerste deel van het Allerød-interstadiaal (2a1) zoals dat in dit proefschrift beschreven is.

In Nederland zijn door diverse instituten in de afgelopen decennia meer dan 400 pollendiagrammen van het Laatglaciaal vervaardigd. Voor het samenstellen van een databestand van de gegevens van meer dan 250 pollendiagrammen is gebruik gemaakt van de structuur van de European Pollen Database. Voor de berekening van de pollenpercentages is uitgegaan van een standaard pollensom die een goed beeld geeft van de regionale vegetatie. In deze pollensom zijn daarom alleen landplanten en dus geen water- of oeverplanten opgenomen. Voor de correlatie van de verschillende pollendiagrammen is een regionaal zoneringsysteem opgesteld. Veranderingen in de pollenpercentages van *Betula* (berk) en *Pinus* (den) zijn het belangrijkst. Verder zijn veranderingen in de percentages van AP (boompollen), NAP (niet boompollen), *Salix* (wilg), *Juniperus* (jeneverbes), *Populus* (populier), *Artemisia* (bijvoet) en *Empetrum* (kraaiheide) gebruikt voor de zone-indeling.

Vegetatie en klimaat

De analyse van de relaties tussen vegetatie, klimaat en het abiotisch landschap vereist een goede tijdscontrole. Veranderingen in de vegetatie die door verschillende auteurs gedateerd zijn met behulp van de ^{14}C-methode vormen na een kritische evaluatie van de betreffende dateringen de basis voor het tijdskader. Het blijkt dat dateringen goed bruikbaar kunnen zijn, mits kritisch beschouwd en geplaatst in een regionale context. Op basis van 239 ^{14}C dateringen uit een totaal van 102 pollendiagrammen uit Nederland en directe omgeving is de vegetatie-ontwikkeling opgehangen aan de ^{14}C-tijdschaal.
Veranderingen in de pollensamenstelling die gerelateerd kunnen worden aan temperatuur dalingen komen voor bij 12.100, 11.500, 10.950 en 9.950 BP. Door het vastgestelde tijdskader kunnen deze veranderingen vergeleken worden met fluctuaties in zuurstof-isotopen van Groenlandse ijskernen en Zwiterse meer-afzettingen. Het blijkt dat deze fluctuaties in zuurstof-isotopen en de vegetatie goed met elkaar overeenkomen, en dat het klimaat dus de sturende factor geweest is voor de grotere vegetatie veranderingen.

Vegetatie en landschap

Het landschap in het Laatglaciaal was onderhevig aan sterke veranderingen in zowel geomorfologie als vegetatie. Gedurende het Laatglaciaal waren diverse geomorfologische processen actief, maar niet zo intens als tijdens het Pleniglaciaal. De processen die te koppelen zijn aan de aanwezigheid van permafrost verdwenen gedurende het Laatglaciaal. Met name eolische en fluviatiele processen waren actief in het Laatglaciaal.
In het algemeen kunnen 5 laatglaciale landschapstypen worden onderscheiden, die gekenmerkt worden door specifieke geomorfologische processen en vegetaties. Deze landschapstypen zijn: het stuwwal-landschap, keileem-landschap, löss-landschap, dekzand-landschap en rivier-landschap.
Een belangrijke factor voor geomorfologische processen zoals winderosie, duinvorming en rivierinsnijdingen of veranderingen in het rivierpatroon is de erosiegevoeligheid van de ondergrond. Stabilisatie van de ondergrond door vegetatie en bodemvorming is daarom een factor die van belang is voor de intensiteit van geomorfologische processen. De rol van de veranderende vegetatie-samenstelling gedurende het Laatglaciaal is daarom niet onbelangrijk.

De vegetatie-ontwikkeling tijdens het Laatglaciaal is in de eerste plaats bepaald door veranderingen in klimaat en in de tweede plaats door standplaatsfactoren als lithologie, geomorfologie en waterhuishouding. Pollendiagrammen uit verschillende landschapstypen die dezelfde periode beslaan, laten vaak onderlinge verschillen zien in vegetatie-ontwikkeling die niet alleen verklaard kunnen worden door klimaatverschillen. De constructie van iso-pollen kaarten voor de belangrijkste pollen-typen per tijdsnede geeft een inzicht in de ruimtelijke verspreiding van taxa. Het dichte netwerk van palynologische gegevens in Nederland maakt het mogelijk om hoge-resolutie kaarten te construeren voor de onderzochte periode. Er blijken duidelijke relaties tussen de iso-pollen patronen en landschaps-type te bestaan.

Case-study Gulickshof

Aan kalkgyttja-afzettingen bij Gulickshof, Susteren, zijn Laatglaciale milieu-veranderingen bestudeerd. De resultaten van onderzoek aan pollen, macro-resten, zoetwater mollusken, stabiele isotopen ($\delta^{18}O$ en $\delta^{13}C$) en geochemische analyses zijn gecombineerd voor de interpretatie van laatglaciale milieu-veranderingen. Het pollendiagram Gulickshof toont een continue vegetatie-ontwikkeling vanaf het Bølling interstadiaal tot in het Late Dryas stadiaal binnen een meer-afzetting met een dikte van 2,9 meter. Het met de ^{14}C-methode gedateerde pollendiagram komt goed overeen met de algemene laatglaciale vegetatie-ontwikkeling zoals eerder geschetst.

Vroeg in het Allerød interstadiaal, rond 11.900 BP, veranderde zowel de samenstelling van aquatische soorten, het kalkgehalte als de isotopen-samenstelling. Deze veranderingen kunnen worden verklaard door fluctuaties in de grondwaterspiegel als gevolg van het afsmelten van de permafrost. Het voorkomen van permafrost is daarom een belangrijke factor voor veranderingen in de grondwaterspiegel en vegetatie in het Laatglaciaal. Het definitieve afsmelten van de permafrost zorgde voor een tijdelijke daling van de (schijn) grondwaterspiegel gevolgd door een snelle stijging en aanrijking met grondwater vanuit de diepere ondergrond. Dit laatste komt tot uiting in de aquatische vegetatie en de stabiele isotopen samenstelling. Aangetoond kan worden dat dit moment bereikt wordt vroeg in het Allerød interstadiaal, rond 11.900 BP.

Conclusies

Hoewel er gedurende het Laatglaciaal en Vroeg Holoceen verschillen in vegetatie-samenstelling bestonden in de ruimte, zijn de grotere veranderingen in de tijd over Nederland synchroon. Deze algemene trends in de vegetatie-ontwikkeling zijn het gevolg te zijn van klimaatveranderingen terwijl afwijkingen van deze trends het gevolg zijn van lokale omstandigheden.

Naast veranderingen in de vegetatie, waren er ook veranderingen in de geomorfologie, en dan met name in het dekzand- en rivier-landschap. Deze veranderingen in het abiotisch landschap kunnen beter worden begrepen als ook de vegetatie-ontwikkeling bekend is, omdat vegetatie immers een belangrijke factor is bij geomorfologische processen.

Een tot nu toe onbekende factor, namelijk de aanwezigheid van permafrost en het definitieve afsmelten daarvan vlak voor het Allerød-interstadiaal is van grote invloed geweest op de ontwikkelingen in geomorfologie en vegetatie in deze periode.

Samenvattend kan gesteld worden dat het mogelijk is om door middel van een palaeogeografische benadering een beter onderscheid te maken tussen de invloed van klimaat en abiotisch landschap op de vegetatie-ontwikkeling.

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Curriculum Vitae

Wim Hoek werd op 30 januari 1966 geboren te Culemborg. Van 1978 tot 1984 bezocht hij het Koningin Wilhelmina College in Culemborg, waar hij in 1984 het VWO diploma behaalde. In augustus 1984 werd begonnen aan de studie Fysische Geografie aan de Rijksuniversiteit Utrecht waar in augustus 1985 het propedeutisch diploma werd behaald. In zijn verdere studie specialiseerde hij zich in de Geomorfologie en Kwartairgeologie. Naast een bijdrage aan de kartering van het rivierengebied tijdens diverse student-assistentschappen, werd voor het doctoraal onderzoek dieper ingegaan op de kwartairgeologische ontwikkeling van het Land van Maas en Waal.
In het kader van het doctoraal bijvak Palynologie/Paleobotanie bij het Laboratorium voor Paleobotanie en Palynologie (RUU) werd veldonderzoek uitgevoerd in Frankrijk, Spanje en Portugal. Van een hoogveen uit de Monts du Forez (Frankrijk) werd een boorkern palynologisch geanalyseerd. Een stage werd gevolgd bij District Midden/Oost van de Rijks Geologische Dienst te Lochem. Hierbij werden lithologische boorbeschrijvingen geconverteerd naar geo-hydrologische kolommen.
In 1990 studeerde de auteur af waarna hij bij de Rijks Geologische Dienst te Haarlem advieswerk verrichtte voor de Dienst Grondwater Verkenning TNO. Van januari 1991 tot juli 1991 werkte hij als projectleider Geomorfologie bij Rijkswaterstaat (RIZA) afdeling Algemeen Onderzoek Fysica te Arnhem.
In augustus 1991 werd als onderzoeker in opleiding, aan de Faculteit der Aardwetenschappen van de Vrije Universiteit te Amsterdam, begonnen aan het door NWO gesubsidieerde onderzoek met als titel: *Paleogeografie van Laatglaciale Vegetaties: analyse in ruimte en tijd* dat uitmondde in dit proefschrift. Vanaf januari 1997 is de auteur werkzaam als universitair docent in de paleo-ecologie van sedimentaire milieus aan de Faculteit der Aardwetenschappen van de Vrije Universiteit te Amsterdam.

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